INTERNATIONAL COMPARATIVE ANALYSIS ON URBAN TRANSPORTATION ENERGY CONSUMPTION

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Preface

This research is the one of the challenges for contribution to the sustainable development concerning the environment and overcoming motorization. There are plenty of researches that outline motorization, and the other reasons for moving beyond the automobile age. Beginning with the significant contribution of Newman and Kenworthy's works in relation to the importance of denser urban structure, especially, many of new theories and researches related to reducing transportation energy consumption or characteristics on urban structure, a research on travel behaviors has been conducted as an effort to achieve sustainable development.

In this way, this research is positioning on the current research stream on diagnosing the automobile dependence in an international scale, and suggesting that the importance of the initiatives related to urban policy on reforming urban density and introducing new public transport system as an alternative mode of private motorized modes.

Energy impact of transport is a strong reflection of the degree of dependence of private passenger vehicles in a city. The awareness of this became a personal motivation of this research. And the point that how should we overcome automobile dependence is the major interest and the way of whole research process in this study.

According to Mee's (2009) writing, "Public transport is not the only alternative to the private motorized modes, but it is a necessary ingredient in a post-automobile future. Unless public transport is so convenient that it offers real competition to the car, then schemes to promote walking and cycling, and restrain the use of car" (Mees, 2009) This shows clear connections to the fundamental way that transportation influences the shape of cities and how we live. The basic content of this research is related to the need to reassert the importance of those who plan transport infrastructure and land use in cities. In particular, the central question is how to make a city less dependent on the private motorized modes, and how we should utilize public transport for achieving sustainable development of a city as mentioned above.

However, it does not currently seem to be adequate to examine the relationship between environmental impact and public transport and automobile dependency even though much research which related to planning method for sustainable urban development and inquiring into the interaction of travel behaviors and various urban characteristics has been conducted to reduce energy use of transport. Particularly, it seems necessary to conduct comparative research targeting more cities in the world that oriented by their own characteristics of economic standard, urban density, personal characteristics etc., which impact travel behaviors and transportation energy consumption. Therefore, this research is targeting the 119 cities of 38 countries.

There are many objectives in studying cities and collecting data on transportation and urban density etc. And this research has clarified the diversity of many relationships between the social, economic and environmental aspects of urban life that are determined by the city's transport patterns and how the city is shaped.

Of course, there are many arguments of the viewpoint on achieving sustainable development. However, I hope this study could be a significant contribution to it.

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List of abbreviations

A	
AHP	Analytic Hierarchy Process
B	
BEA	Bureau of Economic Analysis Regional Economic Accounts
BTS	Bureau of Transportation Statistics
C	
CBD	Central Business District
CCR	Charnes Cooper Rhodes Model
CO_2	Carbon Dioxide
CVM	Contingent Valuation Method
D	
DEA	Data Envelopment Analysis
DMUs	Decision Making Units
F	
FHWA	Federal Highway Administration U.S. Department of Transportation
G	
GDP	Gross Domestic Product
GHG	Green-House-Gases
GRDP	Gross Regional Domestic Product
H	
HOV	High Occupancy Vehicle
I	
ICC	Intra-Class Correlation
J	
JICA	Japan International Cooperation Agency
K	
kEP	kilogram Equivalent Petrol
L	
LRT	Light Rail Transit
M	
MCD	Mobility in Cities Database
MLITT	Ministry of Land, Infrastructure, Transport and Tourism
N	
NHTS	National Household Travel Survey
NMM	Non-Motorized Modes
NMT	Non-Motorized Transport

O

OD	Origin and Destination of trip

P

PMM	Private Motorized Modes
PT data	Person Trip data

S

SUV	Sports Utility Vehicle

T

TDM	Transit Development Management
TOD	Transit Oriented Development
TJD	Transit Joint Development
TND	Transit Neighborhood Development
TFD	Transit Focused Development

U

UITP	International Association of Public Transport

V

VKT	Vehicle Kilometers Traveled
VMT	Vehicle Miles Traveled

CHAPTER 1

Introduction

1.1 Research background and purpose

In recent years, growth in car use is causing an increasing number of problems in each city in the world. People's travel range has expanded due to a motorization parallel to economic development, and urban structure is changing with suburbanization. Moreover, transportation energy consumption is increasing and it has caused serious urban problems, such as air pollution and excessive energy consumption in the urban environment. (Nakamura et al., 2004)

This situation is only expected to worsen because of two trends which have been observed worldwide. First, as mentioned above, the general increase in the standard of living with economic development (Salvatore, 2004). Second, as economies develop so people's reliance on faster transportation modes since individuals are only willing to spend so much time travelling (1.1 hour/day on average). Consequently, the world is shifting toward faster modes, which also are more energy intensive (Schafer, 1999).

Since fossil fuels are the main source of energy, emissions of combustion by-products are also expected to increase. Developing countries are expected to account for 52% of the total worldwide mobility in 2050 with 54,545 billion passenger kilometers while industrialized countries share will shrink from 53% in 1990 to 41% in 2050 (Poudenx, 2008). An increase in the number of private vehicles has already been observed in many countries, with the annual rate at more than 10% in Chile, Mexico, Korea, Thailand, Costa Rica, Syria, Taiwan (Gakenheimer, 1999). Especially, in China, an annual rate of increase of 4% in oil consumption experienced in the past 20 years China's oil consumption resulted in 210 million tons in 2000 (He et al., 2005).

Improvements of individual mobility through economic development and the progression of motorization are accelerating suburbanization (Eom and Schipper, 2010). Furthermore, the increase of trip length as a result of suburbanization is directly linked to increases in transportation energy consumption. This makes it difficult to say that the policies for reduction of automobile use and transportation energy reduction have been successful. In this way, motorization is increasing steadily every year as the economic level of cities develops with time.

However, there is limited research regarding the characteristics on travel behaviors from the viewpoint of economic level for understanding the relationship between urban structure, travel behaviors, and transportation energy consumption. In addition, quantitative analysis of the impact of travel characteristics on transportation energy consumption based on economic level is insufficient. Moreover, as time progresses traffic demands from private modes of transportation are increasing parallel to economic development worldwide. We have to establish strategies that can improve the energy consumption and urban-transport problems, from a traffic perspective, in order to mitigate the motorization. Therefore, it is critically important to not only estimate the transportation energy consumption of a city, but also to clarify how the relationship between transportation energy consumption and individual travel behaviors differ based on economic status.

Meanwhile, many planning techniques and research projects have aimed to develop urban structure based on the concept of sustainable development. In Europe, the concept of the compact city is well-received and urban planning related to constructing efficient urban space is underway. In Japan, compact cities have even been specified as a basic policy of urban planning (Taniguchi et al., 2008). Since suburbanization with low population density and increasing trip length are connected with increasing transportation energy consumption (Choi et al., 2011), it is indispensable to control an individual's travel behavior for reducing transportation energy consumption, and it is important to understand the urban-transport factors according to the development of transport infrastructure. Especially, rail development in cities contributes to reducing transportation energy consumption.

However, the size of effects on reducing transportation energy consumption could be different from cities at the condition of rail development. Therefore, it is significantly important to clarify how the relationship between transportation energy consumption and individual travel behaviors differ according to the rail development.

On the other hand, in this connection on the effect of railway system, Winston and Langer (2004) indicated that congestion costs of Private Motorized Modes (PMM) decrease in a city as rail transit mileage expands. Traffic congestion growth rates declined in several US cities after Tram service was established. Baum-Snow and Kahn (2005) found significantly lower average commute travel times in areas near rail transit than in otherwise comparable locations that lack rail, due to rail's higher travel speeds compared with PMM or bus under the same conditions. In addition, Litman (2007) shows that congestion delay per capita is significantly lower in cities with high quality rail transit systems than in otherwise comparable cities with little or no rail service. Rail system expansion generally occurs in large and growing urban areas in response to increasing congestion. As a result, simplistic analysis often shows a positive correlation between rail transit and energy consumption by congestion.

Likewise, the development of rail systems can be on the rise as an alternative for lightening car dependence that can be the main cause of excessive transportation energy consumption. Understanding the factors of individual characteristics that influence daily travel behaviors (mode choice, trip number etc.) according to the development of rail systems is important. It has been estimated that travel patterns is different according to the development of infrastructure.

In this way, rail transit has come into the spotlight for realizing transit oriented development, providing a good service on transportation, and reducing congestion.

Accordingly, for de-motorization and sustainable urban development, estimating car dependency and railway development are crucial factors in terms of assessing how the balance between demand of determinant in energy consumption and the alternative can absorb traffic demands in urban areas worldwide. Furthermore, international comparative research on the relationship between transportation and land use has generally been limited either to comparisons of aggregate national data or to qualitative discussion (Giuliano and Dargay, 2006). These include Newman and Kenworthy's researches that found an inverse relationship between urban density and fuel consumption per capita (Newman and Kenworthy, 1989a, 1989b).

However, it does not currently seem to be adequate to examine the relationship between transportation energy consumption and rail development and passenger car dependency even though much research which related to planning method for sustainable urban development and inquiring into the interaction of travel behaviors and various urban characteristics has been conducted to reduce transportation energy consumption. Particularly, it seems necessary to conduct comparative research targeting more cities in the world that oriented by their own characteristics of economic standard, urban density, personal characteristics etc. which impact travel behaviors and transportation energy consumption.

To cope with these backgrounds, this research built a database of cities, as a first step of this research, concerning transportation energy consumption of private motorized modes reflecting travel behaviors calculated by data which can be evaluated and aggregated an individual's travel behaviors in detail from 119 cities in 38 countries. (In the case of European cities, data was obtained from the Mobility in Cities Database (MCD) provided by the International Association of Public Transport (UITP). And in the case of Japan, Korea, USA and developing countries, data (Person Trip data) was obtained from the research institutes in each country). Next, considering the difference in economic levels of cities around the world, a discriminant analysis was conducted to evaluate the relationship between urban density and transportation characteristics. Based on the results of the analysis we examined the correlation between urban density and transportation energy consumption by economic level. Analysis showed that the correlation between urban density and transportation energy consumption differs by the city's economic level. Additionally, the more economic development, the clearer the correlation between urban density and travel behaviors becomes. And then, subsequently, Data Envelopment Analysis (DEA) was used as an assessment method to evaluate the efficiency of transportation energy consumption by considering the diversity of the urban traffic features in the world cities. Finally, we clarified the current condition of consumption efficiency by attempting to propose a target values for improving transportation energy consumption.

1.2 Research flow

This research is mainly composed by following 6 CHAPTERs in Figure 1-1.

CHAPTER 1 Introduction

↓

CHAPTER 2 Literature survey

・Estimation on transportation energy consumption
・Urban structure ・Travel behavior ・Economic level
・Infrastructure(Road, Railway) ・Urban policies, etc.

↓

CHAPTER 3
Development of estimation method for transportation energy consumption and building a database on travel characteristics in the world

- Setting target cities
- Collecting data (Person Trip (PT) data, statistical data on demographic, traffic condition, economic state and transportation infrastructure etc.)
- Development of estimation method on transportation energy consumption of private motorized modes
- Assessment the causal relationship between urban density and travel behaviors, transportation energy consumption

↓ ↓

CHAPTER 4
Relationship between urban density, travel characteristics and transportation energy consumption according to economic level

- Classification targeting areas according to economic level
- Analysis the relationship between travel behaviors, urban density and transportation energy consumption based on economic development with utilizing *Discriminant analysis on urban density*
- Assessment on urban density and characteristics of travel behaviors based on the economic level
- Grasping the difference of correlation between urban density and travel behavior, transportation energy consumption
- Reconfirming of the relationship between urban structure, travel behaviors and transportation energy consumption according to top/bottom 15% by economic level

CHAPTER 5
Estimating the efficiency of transportation energy consumption considering urban transportation infrastructure and travel characteristics

- Defining the efficiency on transportation energy consumption in this research
- Classification of cities according to development of transportation infrastructure (road and railway)
- Assessment of the efficiency on transportation energy consumption by utilizing *Data Envelopment Analysis (DEA)*
- Comparison the efficiency by the development of transportation infrastructure (road and railway)

↓ ↓

CHAPTER 6 Conclusions

Figure 1-1 Research flow

1.3 Outline of this research

Transportation energy consumption is a strong reflection of how much dependence of private passenger vehicles there is in a city. The awareness of this became a personal motivation of this research. And the point that how should we overcome automobile dependence is a major interest and direction of whole research process in this study. There are many objectives in studying cities and collecting data on transportation and urban density. In addition, there are so many relationships between the social, economic and environmental aspects of urban life that are determined by the city's transport patterns and how the city is shaped. Therefore, there are many aspects of urban-transport that lie behind this study all of which have a connection to the major topic. It is how we can reduce automobile dependence in cities.

This research is generally composed with six large contents. A brief summary of each chapter as bellowed.

In CHAPTER 1, general introduction regarding research backgrounds, research scope, and expected contributions are discussed. This part mainly explains why we need to grasp the urban-transport programs resulted from motorization in the world with progressing economic development, and achieve sustainable development. And also, it is strongly recommended how this research should be utilized for urban-transport planning in the future with introducing basic philosophy of this study.

In CHAPTER 2, research trends related to sustainable urban development strategies from the aspect of urban-transportation are introduced. According to previous research on urban-transport, new theories and researches related on reducing transportation energy consumption or characteristics on urban structure, travel behaviors have been recently developed as the efforts for achieving sustainable development from the level of city to regional planning. Especially, urban structure, which explained by population or job density affecting travel behaviors, improvement of infrastructure on rail transit and urban policy for mitigating dependence on private motorized modes have been the key driver for sustainable development and reducing transportation energy consumption in the world. In this context, I first organize the previous researches according to the aspects of urban-transport and illuminate the difference of purpose in this research with finding out research trends on sustainable urban development lately.

In CHAPTER 3, development of estimation method for transportation energy consumption considering individual travel behaviors by private motorized modes is suggested for improving conventional method which measures the total consumption of fuel in a city by applying statistical data of the total amount of fuel sold. And then convert total consumed solid fuel into energy per unit amount of fuel. Since, conventional method does not provide the information on the type of vehicle in the travel and individual travel characteristics on person level. Therefore, this research is focusing on individual travel characteristics with Person Trip data (PT data) which can consider individual travel behaviors based on household. And also, I built a database on travel characteristics in the world targeting Asia, Europe, USA and developing countries. In this chapter, I conduct comparative analysis on the relationship between urban density and travel characteristics for grasping the causal relationship of them.

In CHAPTER 4, the difference between urban density and travel characteristics, transportation energy consumption according to economic level is clarified.

The purpose of this chapter is to reveal the relationship between a city's urban density, travel characteristics and economic development. For this I divided the cities by population density and proved the strong correlation between urban density and traffic characteristics through discriminant analysis. And then I divided the cities by their economic development to prove that urban density, traffic characters and transportation energy consumption has a stronger correlation with more economically developed cities.

Travel behavior is the result of comprehensive urban-transport activities. And, it is certain that traffic demand of private motorized modes parallels economic development worldwide to the extent that it increases in economic levels. Especially, the correlation between urban density and travel characteristic of PMM is becoming stronger as economic level increases. In this context, it is possible to conjecture that urban sprawl could go along with economic development making automobile dependency stronger

In CHAPTER 5, the efficiency of transportation energy consumption in city is estimated by applying Data Envelopment Analysis (DEA). In here, it is defined that the efficiency of transportation energy consumption in this research is creating more economical value with less transportation energy consumption of Private Motorized Modes (PMM). Efficiency was considered from the two aspects of economic level and travel behaviors. This means that this chapter attempted to observe how much economic value (GRDP and trips by private motorized modes and public modes which means the result from the production activity in a city) is created by less transportation energy consumption of PMM. Especially, grasping the impact of the diversity of urban transportation infrastructure is very important to improve transportation energy efficiency so that I classified the target cities to five urban types by the development of rail systems around the world. Then, this research investigated the efficiency of transportation energy consumption and compared how the efficiency is different according to rail systems. Finally, I clarified that well-constructed railway systems based on higher urban density have meaningful relationship with realizing higher efficiency of transportation energy consumption.

CHAPTER 6 is a part for making a knot with integrating overall research contents and findings of this paper. From CHAPTER 3 to 4, it was clarified that causal relationship between urban density and transportation energy consumption with utilizing Person Trip data (PT) is significant. In addition, the trends in the world on transportation energy consumption were comprehended according to economic level. Up to this part, urban density and economic level of city are focused as important factors for explaining influence on travel behaviors and transportation energy consumption. Next, in CHAPTER 5, it is assessed that the efficiency of transportation energy consumption based on urban type explained the development of rail systems. According to the development of rail system, efficiency of transportation energy consumption and travel behaviors by private motorized modes and public modes are different. Consequently, it was clarified that denser urban structure, with well-maintained railway systems (such as Metro + Tram or Metro), could refrain use of the private vehicle and transportation energy consumption, and encourage public transport. Therefore, it seems that denser urban structure and well-constructed and linked railway systems can be prerequisite for realizing higher efficiency of transportation energy consumption.

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CHAPTER 2

Literature survey

2.1 Overview of this chapter

Rapid urbanization has brought many changes in modern transportation infrastructure and transport behavior. With the increase of private transportation coupled with an inadequate supply of public transportation, urbanization has accelerated the carbon footprint left by transportational means as well as other environmental impacts. It has been proven that denser urban structures lead to the decentralization of population and private activates increasing the fuel consumption in an exponential manner. Also the decrease in traffic speed shows an inverse proportional relationship with fuel emissions.

Numerous researches have been conducted on the relationship between urban density, travel behaviors and transportation energy consumption since the 1970's. The research has continued to the present day where the focus is now on the development urban structure to promote sustainable development. Topics of such interest circle around questions such as: which aspects of urban structure are most relevant to travel behavior? And how should urban structure be built—urban environment characteristics vis-à-vis other factors known to affect the amount of travel demand?

An important contribution to the literature on the impact of urban structure is the work of Newman and Kenworthy (1989a, 1989b) which focuses on the relationship between land use and travel characteristics in 32 major cities located in Europe, North-America, Australia and Asia. Their results on the inverse correlation between population density and transportation energy consumption has become a world famous finding indicating that it is important to have high residential densities mixed in with employment activity if there is to be much less dependence on private automobiles. And the requirement for transit investments and re-urbanization—concentrating development in the higher-density inner areas and along rail corridors within the metropolitan area—found much response among policymakers in Europe and the USA. Their work have been developed as a leading theory on the relationship of spatial composition of urban structure and transportation energy consumption, so that various aspects, such as urban density and urban mobility, sustainable development and population density, sprawl and concentration, urban density and transportation energy consumption and is considered in policy development.

Along with this, the search for effective policy measures to reduce automobile dependence and its associated negative social and environmental impact has been a major focus on academic research throughout the past few decades. The most commonly adapted policy focuses on limiting the transportation demand. This includes the restrain of automobile use through imposing road prices, parking control and traffic calming, and/or increasing transportation supply, including road construction, rail investment and providing park-and-ride facilities as an alternative (Givoni and Rietveld, 2007).

However, it is recognized that policy measure focusing only on transportation issue can bring limited results. It means that there are many other factors influencing travel behaviors. As mention above, urban density or land use are important also factors influencing travel behaviors.

According to Amulya (2000), some of the strategies and broad plans to achieve sustainable development in transportation is (1) Minimization of dependence on petroleum fuels, (2) Maximization of the level of safety, comfort and time-saving services, (3) Maximization of the environmental soundness of the transport system and others. And also, he asserted detailed policies to implement the above strategies for achieving a sustainable transport system:(1) Transport-energy database generation and use, (2) Improvement of the capacity and quality of road infrastructure, (3) Traffic management, (4) Improvement of railways, and so on.

And also, Loo (2010) identified that the principles of Transit-Oriented Development (TOD) are the basic ideas to design an urban form in a relatively high density, compact and mixed form, and to provide high quality, efficient mass transportation services, together with a pedestrian friendly environment. In addition, other strategies for development, such as smart growth, Transit-Joint Development (TJD), Traditional Neighborhood development (TND) and Transit-Focused Development (TFD), have been proposed. Although the meanings of these terms are not exactly the same, they share some common elements, such as the promotion of mixed development close to public transit.

Apart from the urban structure, the researched related to the relationship between urban form and public transit influencing people's travel behavior has been conducted as well.

Podobnik (2002) indicated that households significantly reduce their vehicle travel when they move to transit-oriented locations with studies that account for demographics and preferences, including some before-and-after studies. Market surveys indicate that demand for transit oriented development will increase in the future, suggesting that rail transit development can provide significant future benefits. In addition, Khanna et al., (2011) examined the impact on transportation energy consumption that can take place after the introduction of alternative public transport systems with targeting Delhi in India. In this context, increased bus-transit and metro rail are compared with a business as usual scenario. They showed that a bus dominated transit system would result in 31% reduction in transportation energy consumption, while for a metro rail dominated transit system it would be 61 % based on a 2005 study.

From a policy perspective, the disagreement and confusion about the relevance of urban structure is unfortunate, as it creates uncertainty among policymakers about what strategy to pursue when attempting to make travel patterns more sustainable.

And also, Litman (2007) insisted that rail transit is a solution of traffic congestion and re-urbanization as an alternative mode of private vehicles.

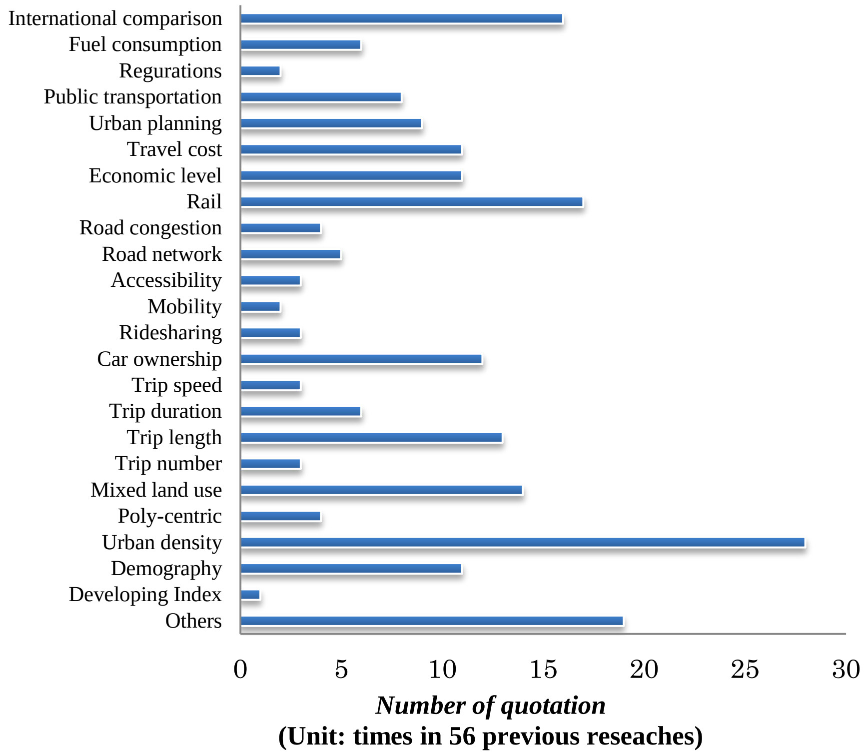


Figure 2-1 Major research fields related to urban transportation energy consumption

To cope with these backgrounds, it is possible to say that there is growing concern about the negative environmental and energy effects caused by transportation systems and related land-use patterns.

In this research, I organized the research tendency on transportation energy consumption in Figure 2-1. This figure is made up by arranging the key words which considered as major factors in the latest researches of the world related to transportation energy consumption. In broad outlines, the key words are categorized in several patterns (Urban density, Travel characteristics, Trip purpose, Transportation infrastructure and Urban policies etc.).

I extracted 56 studies from the journals of '*Transport policy, Energy policy, Transportation research A～E*', and so on for grasping the research tendency and an issue to be treated in the further research on transportation energy consumption. (Detail information of the researches in Figure 2-1 is organized in "Table A" of APPENDIX at the final of this thesis.)

Figure 2-1 shows that urban structure which explained with urban density and mixed land use is significantly quoted as a major factor on travel behaviors and transportation energy consumption. Meanwhile, as an important issue from the aspect of transport, characteristics on a rail transit are the most commonly considered and also the research on urban planning which combines rail system and land use is coming into the spotlight for reducing automobile dependence. Travel behavior and land-use are a function of one another, therefore it is often hypothesized that changing urban structure or land use can result in changes in energy consumption of transport.

In this way, it is possible to roughly sum up the major issues in the research field related to de-motorization to Urban density, Travel characteristics, Public transit, policy and so on. Urban structure which explained by population or job density affecting travel behaviors, as a popular finding of Newman and Kenworthy (1989a, 1989b) suggests that there is a strong negative correlation between urban density and transportation energy consumption, improvement of infrastructure on rail transit might be the main factors for sustainable development and reducing transportation energy consumption in the world. Therefore, this research mainly focused on the studies related to these urban-transport factors as literature survey.

2.2 Urban density influencing travel behaviors and transportation energy consumption

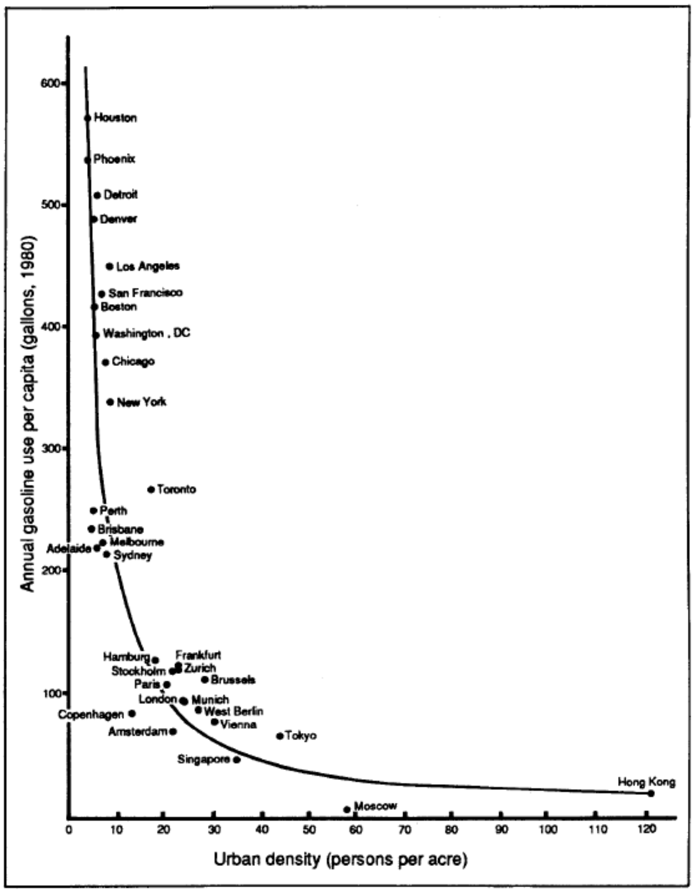
Urban sprawl is a multifaceted concept, which includes the spreading outwards of a city and its suburbs to its outskirts to low-density and auto-dependent development on rural land, high segregation of uses (e.g. working place and residential), and various design features that encourage car dependency. Urban sprawl, which explained by decentralization (spread of population without a well-defined center), discontinuity (leapfrog development), segregation of uses, generally has negative meaning due to the health, transportation and environmental issues. Especially, in the term of urban planning, urban sprawl is controversial with growth of car dependence.

People's travel range has expanded due to motorization parallel to economic development, and urban density is changing with suburbanization. Therefore, we need to grasp the research trends on urban density which affects travel behaviors.

The cities in US are well known as a spread urban structure on high car use. McCann (2001) insisted that the major reason of urban sprawl in the US cities results from that an additional supply of infrastructure is provided at an appropriate time so that travel cost of consumer can be increased. He clarified that 18% in total income of American people is spent only for travel cost. Especially, people in Huston in which urban planning has not sufficiently been established are spending 22% of their total income for their travel cost.

As a result, people in Huston spend 8,800 US$/vehicle/year with including increased travel cost and the average of travel cost is the highest in the US. In addition, it was demonstrated that the travel cost of those who live in sprawled area is spent more 1,300 US$/person/year.

McCann (2001) recommended that it is need to construct more road infrastructures for restraining a sprawl which makes people dependent on private vehicle by government support. Giuliano and Dargay (2006) conducted an international comparative analysis of relationships between car ownership, daily travel and urban structure. Using travel diary data for the US and Great Britain, they estimate models of car ownership and daily travel distance. They found that metropolitan size affects travel only in the largest metropolitan areas of the US. Daily travel distance is inversely related to local population density, but the effect is much stronger for the US than Great Britain. As a result, they conclude that higher transport costs in Great Britain promote economizing behavior, which in turns leads to more consumption of local goods and services and more use of alternative transport modes. Therefore, it is an undeniable fact that urban sprawl has a negative effects on environmental, transportation and economical aspects.



Source: Newman and Kenworthy, 1989a

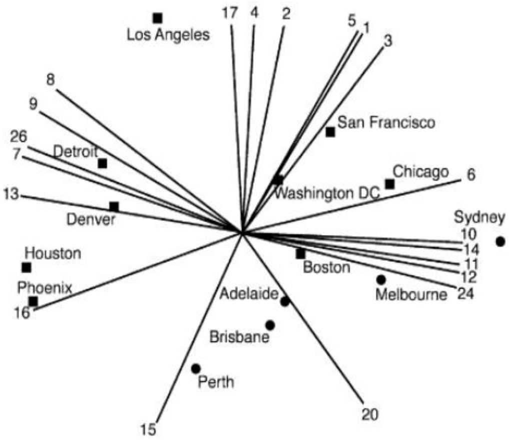
Figure 2-2 Gasoline use per capita versus population density

Related to urban structure, it has been widely demonstrated how important urban structure is in helping to explain the macro patterns of urban transportation, especially the level of automobile dependence and transportation energy consumption (Newman and Kenworthy, 1989a, 1989b, Kenworthy and Laube, 1999; Cervero, 2002).

Population density, the most significant measure of urban structure, is a major indicator of the potential represented by travel behaviors in a city. The higher the density is, the greater the proportion of Non-Motorized modes of transport and public transit is generated. This holds true regardless of economic level of a city. It has also been observed, in Figure 2-2, that the lower the urban density is, the higher transportation energy is consumed (Newman and Kenworthy, 1989a).

Morimoto and Furuike (2002) utilized the past three Person Trip data (1987, 1992, 2001) of Japan for grasping the change of the relationship between transportation energy consumption and urban characteristics. Then, they clarified that in the term of 1987 to 1992, development of road infrastructure and compactness of urban form have worked on restraining energy consumption in Japanese cities. However, in the term of 1992 to 2001, even though cities have compactness or oriented public transport relatively high, it showed that a tendency of transportation energy consumption is increasing due to the complexities of major factors affecting energy consumption, as same to other cities in Japan.

On the other hand, there are contrary viewpoint of urban density on the effect of restrain automobile dependence, and different suggestions on the effect of urban density have become a controversy. To reduce dependence on automobile travel, a group of transportation planners have turned to using density as a planning pool. By modifying the design of our neighborhoods through increasing population density and/or TOD, transportation planners hope that people’s need or desire to use automobiles can be reduced or even eliminated (Cervero and Kockelman, 1997; Chen et al., 2010). However, empirical evidence on this issue reveals an inconsistent picture on the role of urban population density.



Source: Mindali, et al. (2004)

Figure 2-3 Analysis of USA and Australia's cluster

Even though some researches find a statistically significant negative relationship between density and the probability of using private motorized modes (Cervero, 1996; Ewing et al., 2007), others did not find density to have a significant impact on people's travel behaviors and patterns (Mindali et al., 2004; Cervero and Kockelman, 1997).

Several studies directly answer the question of whether transportation energy consumption is correlated with urban spatial characteristics. As mention above, Newman and Kenworhty (1989b) demonstrated that there is a strong negative correlation between urban density and energy consumption of transport. Mindali et al. (2004) questioned the conclusion of Newman and Kenworthy based on the same dataset but a different multivariate statistical technique (Co-Plot), (Figure 2-3). And they concluded that there is no direct relation between urban density and energy consumption. Namely, there is not only one direct relationship between urban density and urban transportation energy consumption, rather than we should consider the relationship between the indicators that represent the urban density in detail and urban transportation energy consumption.

They analyzed 31 cities from USA, Europe and Australia using 26 variables representing urban and transportation attributes (Table 2-1). Figure 2-3 means that each variable is represented individually by an arrow and also arrows located in the same direction represent high positive correlation, those located in an opposite direction (180°) represent high negative correlation, whereas arrows situated as a perpendicular demonstrate no statistical correlation.

Table 2-1 Variables encoding for Co-Plot

Variable no.	Variable	Variable no.	Variable
1.	Urban density	14.	Proportion of workers using foot or bicycle
2.	Employment density	15.	Length of road per person
3.	Outer area density	16.	Parking places/1000 CBD workers
4.	Outer area employment	17.	Total vehicles per km of road
5.	Inner area density	18.	CBD density (person/ha)
6.	Inner area employment	19.	Proportion of population in CBD (%)
7.	Total vehicle/1000 people	20.	Proportion of jobs in CBD (%)
8.	Passenger cars/1000 people	21.	Vehicle km per person (total public transportation)
9.	Per capita car passenger km		
10.	Per capita public transportation passenger km	22.	Passenger trips per person (total public transportation)
11.	Proportion of passenger km on public transportation	23.	Passenger trips per vehicle (buses)
12.	Proportion of workers using public transportation	24.	Avg. speed of public transportation (total)
		25.	Proportion public transport passenger km (on train)
13.	Proportion of workers using private transportation	26.	Total energy use/person (MJ)

Source: Mindali, et al. (2004)

In addition, the location of the target cities means the significance of variable compare to other variables relatively for individual city. Here, Figure 2-3 illustrates the distribution of cities from the US and from Australia. The major distinction is a result of differences in the proportion of jobs in the CBD (variable no. 20), in which the Australian cities reveal a much higher level in comparison to US cities. Australian cities display relatively low energy consumption, rather than the US cities.

"Co-Plot" creates a two dimensional "map" from the conclusion about the relationship between variables can be deducted. Using Co-Plot, an innovative multivariate statistical technique, they could clarify some of the relationships between density and energy consumption in western cities. And they result that there is no direct impact of total urban density. Meanwhile, Su (2011) pointed out that these two studies failed to consider gasoline price and household income. And also, Omitted variable bias could be a concern for their results.

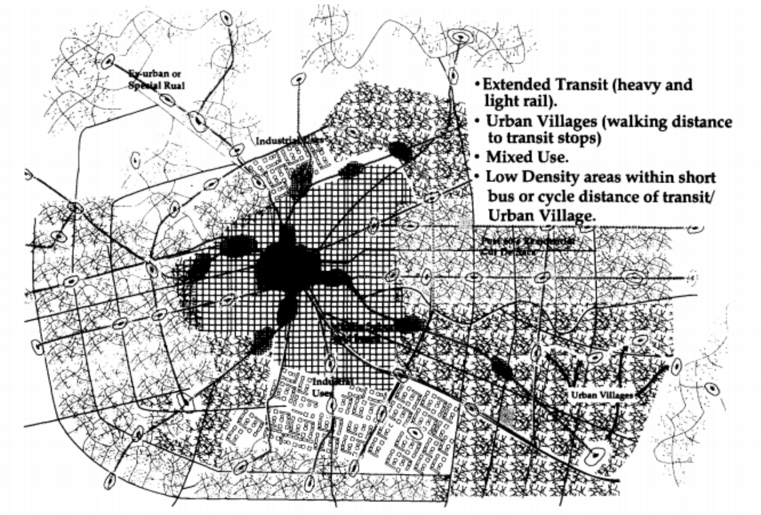
Bento et al. (2005) utilized micro-data to connect city-level urban spatial characteristics with travel demand, and rail supply have a significant impact on annual household VMT, while the impact of population density is not statistically significant. Karathodorou et al. (2010) used 84 cities from 42 countries to investigate the impact of urban density on fuel demand. And they concluded that urban density affects fuel demand, but it has a larger impact on car ownership and distance traveled per car. Small and Van Dender (2007) used a panel dataset and system of simultaneous equation model to estimate the rebound effect. They find that urban density has a negative impact on VMT.

Meanwhile, Banister (1992) conducted analysis on the relationship between transportation energy consumption and urban structure with four major methods. The first is an analysis of the relationship between transportation energy consumption and traffic demand of every mode, trip length, car occupancy in whole urban scale with aggregated data. The second is utilizing non-aggregated data to the first method. By applying non-aggregated data to analysis, the result can reflect the characteristics on social-regional factors which related to travel behaviors. And the third is an analysis which clarifies the relationship between population density and the intensity of land use affects to transportation energy consumption. This method explains that transportation energy consumption is influenced by the intensity of land use which means population or job density is concentrated or not. The forth is an analysis on the relationship between transportation energy consumption and working trip demand which oriented household and workplace. According to Banister, urban structure—explained by urban scale, population density, land use— and traffic demand of each modes, the purpose of travel are main causes of the change on transportation energy consumption.

Whereas, Richardson and Gordon (2001) criticized the effects of the theory on intensive development referred to as centralization with explaining urban sprawl in the US metropolitan areas. They suggested that environmental impacts by car use has decreased gradually due to suburban activity, preference for high-mobility, accelerating the outskirts of the employee ground, an offset effect of commuting distance by increasing commuting speed, the drawback of relocation of residential area around the workplace and the development of low carbon technologies with example for LA urban area. In addition, they explained that the overall benefit of the residents will be reduced from the reason that the high-density development invites the growth of high land prices even though the cost for infrastructure has decreased.

A Different point of view on urban structure apart from urban density is about Mixed land use. Holz-Rau C (1997) analyzed travel length, trip mode and trip purpose according to urban scale with Travel Census data conducted in whole region of Germany so that polycentric urban structure, which qualified mixed land use and green areas, can be effect on restraining automobile dependence. And also, he recommend that mixed land use on one-to-one is effective on restraining car use.

Past researches suggest that mixed land-uses encourage non-auto commuting. However, the results remain ambiguous. Cervero (1996) explored this question by investigating how the presence of retail activities in neighborhoods influences the commuting choices of residents using data from the 1985 American Housing Survey. They clarified that having grocery stores and other consumer services within 300 feet of residence is found to encourage commuting by mass transit, walking and bicycling, with controlling factors such as residential densities and vehicle ownership levels. When retail shops are beyond 300 feet within 1 mile of residences, people tend to utilized private motorized modes for commuting. The presence of close commercial land-uses is also associated with relatively low vehicle ownership rates and short commuting distances.



Source: Newman and Kenworthy (1996)

Figure 2-4 Conceptual future plan of a "Reconnected" automobile city

Overall, they demonstrated that residential densities affected a stronger influence on commuting mode choices than levels of land-use mixture, except for walking and bicycle commuting. And for non-motorized commuting, the presence or absence of neighborhood shops is a better predictor of mode choice than residential densities.

Newman and Kenworthy (1996) overviewed the land use-transport connection as seen in historical context, the patterns of different cities in the world and a series of case studies which demonstrate the new awareness of how to reconnect urban land use and transport. They formed a conclusion that the key characteristics on how land use patterns need to be changed is a conceptual urban form in Figure 2-4 that established new transit systems such as Tram and Metro linked to high-density, walking-based sub-centers. And they suggested that the New urbanism and Transit -oriented planning are well established as means to tackle the host of automobile-based problems through reconnecting land use and transport.

Accordingly, Taniguchi et al. (2008) considered not only population density as a conventional index explaining urban characteristics, but also urban structure in the physical aspects (e.g. shape and position of the commercial areas, placement condition of the city) for grasping the link to environmental impact on transportation at the four points in the past in a multivariate analysis of urban level by utilizing the Person Trip data. As a result, they clarified statistically that the influence of urban spatial structure on CO_2 emission of automobile is slightly lower than population density. In particular, cities with the urban structure concentrated development in the higher-density and along rail corridors within urban area showed that the effect of reducing CO_2 emission from automobile is significant. It could mean that polycentric urban structure is effective on reducing energy consumption of transportation.

Last, Schwanen et al. (2004) clarified the propensity that the higher the density of Inner area, having polycentric urban structure with high job density, the slower speed of private motorized modes is. This propensity may be resulted from the lack of parking place in central area of city and longer trip duration due to the concentration of employment in the Inner area.

From existing researches above, it can be conjectured that denser urban structure seems to come into the spotlight for reducing transportation energy consumption and overcoming automobile dependence even though there are some contrary viewpoints on denser structure.

2.3 Travel behaviors in urban area

Chikanari et al. (2003) expanded the analysis model on minimizing transportation energy consumption with maintaining the level of mobility of cities in Kei-Han-Shin region of Japan as a constraint condition of analysis. And they calculated the traffic volume of each transport mean to demonstrate the effect of reducing transportation energy consumption. As a result, they concluded quantitatively that there is a need to significantly reduce automobile traffic in order to reduce the transportation energy consumption with maintaining the level of traffic mobility.

Lee (2005) targeted the metropolitan areas in Japan and Korea for analyzing and assessing two big policies on urban spatial structure and modal share of public transit in order to reduce transportation energy consumption. He constructed a simulation model based on genetic algorithms by applying urban initiatives to minimize transportation energy consumption with maintaining the level of mobility of metropolitan areas in Japan and Korea. As a result, he shows quantitatively the minimum transportation energy consumption which can be achieved at the moment under the real traffic volume.

Giuliano and Dhiraj (2003) conducted a comparison analysis on travel behaviors with disaggregated individual data of the US and Great Britain. They built the regression model interpreting daily trip number and average trip distance in cities by applying the characteristics on socio-economic and urban structure. The result shows that urban structure has significant effect on travel behaviors and there is a divergence of results within two nations. In general, daily trip number is depends on urban scale. The larger urban area is, the less daily trip number is generated. In addition, trip distance is substantially significant with urban density and the denser urban structure is, the shorter trip distance is. Particularly, the efficiency of population density in the US cities is larger than those of Great Britain.

As a reason, the availability of high-quality public transport regardless population density, mixed land use of the cities in Great Britain are considered as major factors. Therefore, it is possible to say that urban structure with lower population density and high automobile dependence such as the cities in the US makes people more trips despite Richardson and Gordon (2001)'s claims above to the contrary.

Schimek (1996) conducted analysis on the relationship between population density, household income and trip distance by passenger car of the cities in the US. Schimek demonstrated that even if 10% increase of population density, but traveled trip distance narrowly decreased by 0.7%. While, even if 10% increase of household income, and it was possible to find that the traveled trip distance increases approximately 3%. Therefore, however, population density affects the trip distance in the US cities, the effect on reducing trip distance is not strong.

Jacobson and King (2009) estimated the potential fuel saving by considering "Ridesharing" for reducing a fuel consumption and Vehicle Miles Traveled (VMT) with targeting the US cities. And they suggest that if no additional travel is required to pick up passengers, adding one additional passenger for every 100 vehicles would reduce annual fuel consumption by 0.80–0.82 billion gallons of gasoline per year. Meanwhile, if one passenger were added in every 10 vehicles, the potential savings would be 7.54–7.74 billion gallons per year. However, ridesharing requires extra travel to pick up additional passengers, which can reduce and possibly eliminate potential fuel savings. The trade-off between saving fuel and spending time to pick up additional passengers is investigated with finding that ridesharing may not be attractive to travelers averagely, but can be made more attractive by increasing trip costs such as parking and tolls.

Hamilton (1982) conducted the comparison the actual average commuting distance and the minimum of commuting distance obtained by the analysis with considering the case that employment moves from the central urban to outskirts. Hamilton suggested that the actual commuting distance in the US is eight times of the minimum commuting distance and this excess trip is called "Wasteful Commuting". He pointed out that a standard urban model assuming a trade-off between travel costs and land prices is poor for explaining a commuting travel pattern, and there is a possibility that commuting trip can be efficient by exchanging the current residence and workplace.

Based on the fact that the actual decentralization of employment is appeared in the specific sub-centers, White (1988) investigated origin and destination (OD) for commuting that minimizes the total commuting time with consideration on the actual traffic condition by classifying urban space into some zones. And he clarified that the actual ratio of wasted commuting time is only 11% by comparing the actual average commuting time and the analyzed average time for commuting.

Taniguchi et al. (1999) estimated the correlation between modal share of each mode and urban characteristics defined by the component ratio of travel behaviors in a city with Person Trip data of 1992 and the data on socio-economic individual characteristics such as age, car ownership etc. As a result, they clarified that the strong correlation between environmental impact and urban classification by the characteristics on travel behavior. However, they pointed out a necessity of time series analysis for considering the change of socio-economic individual features by time.

According to Lefevre (2010), the coexistence low population density and the development of public transport is difficult in general. Especially, the accessibility to bus stop and railway station from house or working place is the most important for using public transport so that 10minutes walking distance on approximately 800m radius appropriate as a maximum for using public transport.

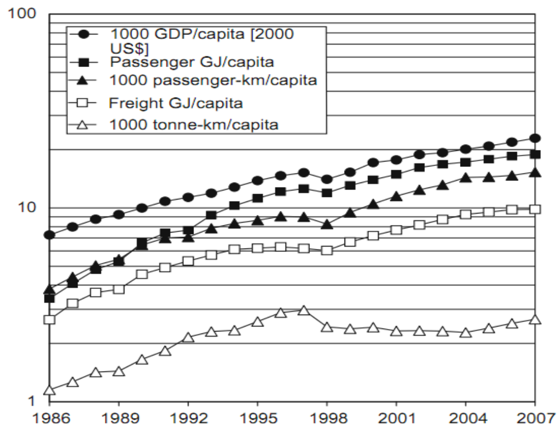
While, Koushki (1991) quantitatively estimated travel costs related to passenger vehicle in household with targeting Riyadh, the capital of Saudi Arabia in where rapid economical development is progressed. He clarified that the increasing fuel price has an effect on the decreasing daily trip number, and also the bigger household is, the less daily trip number is generated. He utilized a multiple regression analysis of Step-wise method with considering passenger car ownership, scale of household, fuel budget in a day as an independent variable.

2.4 Economic development of city making motorization progressing

Rapidly increasing motorization in the world, particularly private automobiles, creates both economic and individual benefits, as well as externalities and indirect negative impacts. Such externalities could be adapted and mitigated relatively easily when the rate of motorization growth is low. However, when the number of private automobiles rises by 15 to 20 percent per year and is heavily concentrated in dense cities, externalities create undesirable environmental and social consequences.

It is especially worthy of analyzing how the transportation energy consumption would interact with the social and economic growth when we demand more of the energy which becomes increasingly rare, and transportation accounts for more of the total energy consumption as a result of economic growth. Here, I investigated the research trend on the relationship between transportation energy consumption and economic development or economic status in a city.

Eom and Schipper (2010) conducted an analysis on rapid growing passenger transport energy consumption in South Korea. They pointed out the importance on having a clear understanding of transport energy use trends is crucial to identifying opportunities and challenges for efficient energy use for the transport sector. However, analysis regarding rapid growing passenger transport energy use in South Korea has not been conducted. Therefore, they described the trends of transport activity, energy use, and CO_2 emissions from South Korea's transport sector since 1986 with a particular focus on its passenger transport with utilizing bottom-up data developed from a variety of recent sources. Figure 2-5 shows per capita GDP, transportation energy consumption, and activity of passenger and freight in South Korea from 1986 to 2007. As you can see, this figure clarifies the relationship between economic development and transportation energy consumption both of private passenger vehicle and freight. An economic index explained by GDP shows the result of social-economic



Source: Eom and Schipper (2010)

Figure 2-5 GDP, energy, and activity of South Korea's passenger and freight transport activities, and a vigorous traffic activity can be causative of more energy consumption of transportation.

As a result, they showed that while travel activity has been the major driver of the increase in passenger transport energy use in South Korea, by classifying the trends in passenger transport energy use into activity, modal structure, and energy intensity, the increase was more or less offset by the recent favorable structural shift toward bus oriented travel and away from car travel. And also, they demonstrated that while bus travel has become less energy intensive since the Asian Financial Crisis (1997), car travel has become increasingly energy intensive.

Recently, Chinese economic development is the explosive in the world. As the Chinese economy improved, the importance of passenger vehicle has been represented by both continuous economic growth and improvement of quality of life. Road transportation has gradually become the dominant part of the transportation system in China so that the amount of oil consumed on the road is increasing with time. Furthermore, the energy situation from road transportation of developed countries is the same as well. He et al. (2005) attempted to present the current status and forecast the future trends of oil demand and CO_2 emissions from the Chinese road transport sector and to explore possible policy measures to contain the explosive growth of Chinese transport oil consumption. They utilized a bottom-up model for estimating the historical oil consumption and CO_2 emissions in road transport sector between 1997 and 2002 and to forecast future trends in oil consumption and CO_2 emissions up to 2030.

As a conclusion, they suggested that China's road transportation will gradually become the largest oil consumer in the next two decades and that China needs to implement vehicle fuel economy improvement measures immediately in order to contain the dramatic growth in transport oil consumption. Because, China is now in a period of rapid growth in passenger car sales and also, Chinese vehicles in the market are relatively inefficient.

Pucher et al. (2005) recommended policy improvements that can help mitigate India’s urban transport crisis in their article related to India’s transport system and travel behavior. They point out that there are two main obstacles to implementing policies needed to deal with India’s urban transport crisis: financial and political problems according to economic development.

Indian cities face a transport crisis characterized by levels of congestion, noise, pollution, traffic fatalities and injuries, and inequity far exceeding those in most European and North American cities. India’s transport crisis has been aggravated by the extremely rapid growth of India’s largest cities in a context of low incomes, limited and outdated transport infrastructure, suburban sprawl, sharply rising motor vehicle ownership and use, deteriorating bus services, a wide range of motorized and non-motorized transport modes sharing roadways, and inadequate as well as uncoordinated land use and transport planning. Therefore, same as Chinese cities, the aggravation on motorized modes will be expected in the near future according to economic development. And the energy consumed by transportation would significantly affect Indian’s overall energy consumption in the near future.

2.5 Railway systems for de-motorization and sustainable urban development

As mentioned above, rail transit has come into the spotlight for realizing transit oriented development, providing a good service on transportation, and reducing transportation energy consumption. Many researchers suggested that there is abundant evidence that high quality, grade-separated transit does reduce urban traffic congestion, and that transit improvements can be cost effective investments. Here, I introduce the researches on the effects on railway system.

Litman (2007) insisted that rail transit is a solution of traffic congestion and re-urbanization as an alternative mode of private vehicles in three ways.

First, high quality transit service can reduce travel time costs to people who shift modes. Even if there is no time saving, perceived costs per hour tend to be lower than driving if the transit service is comfortable (passengers have a seat, vehicles and stations are clean and safe, etc.), allowing passengers to relax and work. Travelers will choose the mode that best suits their needs and preferences for each trip.

The second, grade-separated transit reduces delays on parallel roadways. Urban transportation congestion tends to maintain equilibrium: congestion deters growth in peak-period trips. Reducing the point of equilibrium is the only way to really reduce long run congestion. The quality of travel alternatives affects this equilibrium. If alternatives are inferior, motorists will be more reluctant to shift modes. Improving transit service quality reduces the delay or reduce automobile trips, which benefits all travelers, including those who continue to drive. Various studies have indeed found that door-to-door travel times of motorists tend to converge with those of grade separated transit (Mogridge, 1990; Lewis and Williams 1999; Vuchic, 1999).

Finally the third, rail transit can stimulate Transit Oriented Development (TOD)—compact, mixed-use, walkable urban villages where residents tend to own fewer cars and drive less than if they lived in more automobile-dependent neighborhoods. Although the intensity of congestion, which measured by roadway level of service or average travel speed, tends to increase with development density, per capita congestion costs tend to be lower in TOD because people drive less and have better mobility options.

Meanwhile, Mackett and Sutcliffe (2003) described a methodological framework that can be used to make new urban rail systems more successful. Eight systems in the US and Canada were investigated in the design of the framework. They established the data through interviews with planners and operators. And the estimation of the introduction of rail system was conducted by the criteria on physical characteristics of the urban area, socio-economic characteristic of the urban area, route location, cost, operating polices, transport planning policies, urban planning policies.

Loo et al. (2010) conducted case studies by using the factors of heavy rail systems in New York City and Hong Kong, which are expected to contribute to higher rail transit ridership by using multiple regressions. As a result, they suggest that a combination of variables in different dimensions, including (i) land use, (ii) station characteristics, (iii) socio-economic and demographic characteristics and (iv) inter-modal competition were important in accounting for the variability of rail transit ridership. In particular, station characteristics (CBD dummy, Major interchange station (dummy), Year of operation, Generalized travel cost from station to Midtown) appeared to be the most important dimension in affecting average weekday railway patronage.

Whereas, passenger car ownership has a positive correlation with railway patronage, Therefore, they recommend that higher car ownership can be used as good tool linking railway system(Pick-ups, Drop-offs, Park and ride) and place-specific factors is a major driver for increasing a patronage of railway.

Givoni and Rietveld (2007) focused on two lines of investigation with regard to access to railway stations in the Netherlands. Firstly, the profile of the access and egress modes on journeys to and from railway stations is analyzed. They also examined how the availability of car affects the mode choice on journeys to the station. Secondly, the effect of passengers' perception of the station and of the journey to the station on the overall perception of traveling by rail is estimated. The results show that most of the passengers choose walking, bicycle and public transport to get to or from the railway station and that the availability of a car does not have a strong effect on the choice of access mode to the station. The quality of the station and the access/egress facilities was found to have an important effect on the general perception of traveling by rail.

Kim et al. (2007) analyzed factors that influence the mode choice for trips between home and light rail stations, an often neglected part of a person's trip making behavior. Using transit survey data describing St. Louis Metro Link riders in the United States, they found out that some of the factors associated with increased shares of walking relative to other modes were full-time student status, higher income transit riders, and trips made during the evening. It was also found that crime at stations had an impact. In particular, crime made female transit riders more likely to be picked-up/dropped-off at the station. Females are more likely to be picked-up or dropped-off at night. Bus availability and convenience showed that transit riders that have a direct bus connection to a light rail station were more likely to use the bus. Private vehicle availability was strongly associated with increased probability of drive and park, when connecting to light rail.

Meanwhile, from the aspect of freight, Akerman (2011) estimated a life cycle perspective of Europabanan, a proposed high-speed rail track in Sweden. The life cycle emissions reductions are found to be 550,000 tons of CO_2-equivalents per annum by 2025/2030 with almost 60% of this coming from a shift from truck to rail freight and 40% from a shift from air and road travel to high-speed rail travel. In contexts similar to Sweden, it is an important issue whether a large increase is required in freight rail capacity anyway, due to that high-speed rail investments may not be justified for the passenger markets alone. They also indicated that a substantial share of emissions due to construction of the new railway could be counterbalanced through the reduced need for building and maintaining roads and airports, and for manufacturing cars.

From the material aspect on rail track structure, Milford and Allwood (2010) investigated the CO_2 impact of current and future UK rail track and estimates the material, process and transport emissions associated with construction, maintenance and end-of-life activities for designs at high and low traffic loads. As a conclusion, analysis shows that for current track configurations, track with concrete sleepers has the lowest CO_2 impact, followed by steel, hardwood and softwood. Several potential future rail track designs have been analyzed including embedded rail and double and quadruple-headed rail. All future track designs have a lower impact than current designs, but this improvement is more marked at high traffic loads. Up to a 40% reduction in CO_2 impact could be achieved if the UK rail network was to move from conventional track design to a double-headed embedded rail design. Key levers for reducing the CO_2impact of track are identified as service life extension, traffic load reduction and the selection of low impact track designs.

Qipeng et al. (2009) reviewed relevant researches from both the policy and academic aspects, and then proposed the research objectives, research system with some key issues. Their motive on the research is that analyzing energy consumption factors of different transportation modes' and establishing the comparable selection platform constitute the theoretical basis to achieve the goals of the entire optimization and energy saving of the integrated transportation system is required currently.

This research emphasizes that the contradiction between development of integrated transportation system and limited energy resources can be solved when the comparable selection platform is established considering the developmental concepts and overall arrangement of the integrated transportation system. And also, the technologic economic conditions and actual operational status of each transportation mode should be taken into account.

Ieda et al. (2001) examined the preconditions that affect quality of railway services in Tokyo and its policy implications. Objective evaluation of quality of services makes it clear that further investment to improve them is necessary in the future, and that passengers are willing to pay for it. However, some classic features of railways in Tokyo hinder improvement. Particularly, their organizational structure, characterized as territorial fragmentation, makes it difficult to internalize the external `network' effect and maximize user benefits on a metropolitan scale. Therefore, transport policy needs to transform railway organizations such that they make further investments efficiently from a social cost/benefit point of view. Further, it is also essential to devise new methodologies to stimulate service promotion of railways as a private business, including financial support for investment and organizational transformation.

Litman (2007) suggests that the full benefits of urban rail are ignored in some of the commonly used measures of congestion. There are about a dozen different congestion indicators to choose from (Litman, 2007). Some, such as the *roadway level-of-service* and the *travel time index*, reflect the intensity of congestion delay to vehicles traveling on a particular roadway, and so fail to account for the benefits to people who shift modes or drive less. Other indicators, such as *per capita congestion delay*, account for these additional impacts, and so tend to recognize greater congestion reduction benefits from rail transit.

While, the difference between light rail systems and metro systems is not always distinct, the shift in popularity from metros to light rail implies a shift to lighter systems with simpler signaling, often with street running. These factors all contribute to lower costs, and so can increase the number of cities for which anew urban rail system may be feasible.

Matsunaka et al. (2009) conducted questionnaire survey for measuring total value of LRT (Light Rail Transit), suggesting the value that LRT brings indirectly, with targeting Toyama and Mulhouse in which LRT is introduced. They focused on how much values LRT creates indirectly in urban space by introducing itself, not only the values including convenience or comfort as public transit. In this way, CVM and AHP were utilized in estimating the values, then they clarified that the values on introduction of LRT bring indirectly "the value of being" and it was shown very high in both cities. In addition, the results showed that consciousness and images related to environment and urban space act as major factors on assessment of the value of LRT.

2.6 Urban policies for urban planning and reducing transportation energy consumption

The idea of using Transit-Oriented Development (TOD) in reducing automobile dependency and improving the sustainability of transportation activities has gained wider support in recent years. Research findings have shown that residents living in TOD neighborhood used transit more frequently than people having similar socio-economic characteristics but living elsewhere. Most of the existing studies on TOD and transit ridership used recently developed sites or suburban neighborhoods as case studies. Here, I introduce some urban policies related to urban planning and transport.

As strong criticism for the work by Newman and Kenworthy (1989a, 1989b), on the relationship between land use, travel behaviors and energy consumption, Coevering and Schwanen (2006) expressed about the role accorded to individual travelers and the wider space-time context of cities. They pointed out that the data collected by Kenworthy and Laube (1999) for European, Canadian and US cities in 1990 is not including important variables affecting traffic volume, for instance fuel price, economic status in individual-city level and socioeconomic demography esc. In addition, they suggested that the space-time context of cities should be considered in aggregate-level comparisons of the relations between urban form and transport by the empirical analysis. Policy recommendations based on the original data may be reconsidered and tailored to the space-time context and population characteristics of cities.

Sung and Oh (2011) determined whether transit-oriented development (TOD) planning factors identified from western case studies can be applied to the city of Seoul, Korea, which is characteristic of dense development. The authors illustrated the distributional patterns and characteristics of planning factors such as transit supply service, land use, street network and urban design at each rail station area. To identify effects of TOD planning factors upon the transit ridership at the targeted 214 rail station areas in Seoul.

As a result, they suggest that TOD planning factors can have a significant positive impact in forming a transit-oriented city. They also indicate that some TOD planning factors, compared to low-density cities in Western countries, need to be carefully applied towards Seoul in order to achieve the objective of regenerating a transit-oriented city.

In summary, rather than focusing mainly on increasing development density, it is necessary to concentrate more on such strategies as strengthening the transit service network, increasing the land-use mix index, and restructuring the street networks and urban design to be more pedestrian friendly around rail stations.

Meanwhile, Morrow et al. (2010) investigated different sector-specific policy scenarios for reducing GHG emissions and oil consumption in the US transportation sector under economy-wide CO_2 prices. They analyzed fuel taxes, continued increases in fuel economy standards, and purchase tax credits for new vehicle purchases, as well as the impacts of combining these policies. All policy scenarios modeled fail to meet the Obama administration's goal of reducing GHG emissions 14% below 2005 levels by 2020. Purchase tax credits are expensive and ineffective at reducing emissions, while the largest reductions in GHG emissions result from increasing the cost of driving damping growth in vehicle miles traveled.

According to Amulya et al. (2000), the strong relationship between transport and energy has not received the attention, even though energy is a crucial constraint on transport, and transport is a major determinant of energy demand. Also, many detailed treatments of the transport sector have not scrutinized the sustainability of the present pattern of development of this sector. Further, the prevailing paradigm guiding the development of the sector is made explicit and critiqued because it is often the root cause of its un-sustainability. And, because treatments of transport policy issues tend to proceed without a clear statement of underlying goals and strategies, the entire hierarchy of interventions from goals to strategies to policies has been discussed. Finally, an attempt has been made to deal with both the supply and demand aspects of the transport sector.

Based on these background, to Amulya et al. (2000), recommended the strategies or broad plan for developing the efficiencies on capital-saving, non-import-intensive, affordable, service-oriented, environmentally sound transport system and for achieving his goal of a sustainable transport system. The detail strategies and broad plan on transport system for sustainable development are below (Table 2-2).

(1) minimization of dependence on petroleum fuels, (2) maximization of the level of safe, comfortable and time-saving transport services, (3) maximization of the environmental soundness of the transport system, and in particular, reduction of local and global environmental pollution, (4) minimization of the capital requirements for the transport modal mix that should also include non-motorized transport (NMT), and (5) minimization of the energy used by the transport system without a reduction of the services provided. The detailed policies (plans or courses of action) to implement the above strategies for achieving a sustainable transport system fall into the following categories: (1) transport-energy database generation and use, (2) demand management, (3) technological improvements in road transport, (4) improvement of the capacity and quality of road infrastructure, (5) traffic management, (6) improvement of the railways, (7) improvement of urban transport, (8) providing a niche for non-motorized modes of transport, (9) pollution control and abatement, (10) costing and pricing, (11) modal shifts to achieve a least-cost freight modal mix, (12) modal shifts to achieve a least-cost passenger modal mix, (13) solutions to the transport sector's problems through measures in other sectors, (14) alternative fuels.

Table 2-2 Strategies and broad plans for sustainable transport system

Broad plans for sustainable transport system	
(1)	Minimization of dependence on petroleum fuels
(2)	Maximization of the level of safe, comfortable and time-saving transport services
(3)	Maximization of the environmental soundness of the transport system, and in particular, reduction of local and global environmental pollution
(4)	Minimization of the capital requirements for the transport modal mix that should also include non-motorized transport
(5)	Minimization of the energy used by the transport system without a reduction of the services provided
Strategies of policies for sustainable transport system based on broad plans above	
i.	Transport-energy database generation use
ii.	Demand management,
iii.	Technological improvements in road transport
iv.	Improvement of the capacity and quality of road infrastructure
v.	Traffic management
vi.	Improvement of railway
vii.	Improvement of urban transport
viii.	Providing a niche for non-motorized transport
ix.	Pollution control and abatement
x.	Costing and pricing
xi.	Modal shifts to achieve a least-cost freight modal mix
xii.	Modal shifts to achieve a least-cost passenger modal mix
xiii.	Solution to the transport sector's problems through measures in other sectors
xiv.	Alternative fuels

Appropriate policy instruments or mechanisms for initiating and maintaining the policies as well as suitable policy agents to wield the policy instruments have also been identified. The market has the power of being an excellent allocator of money, materials and manpower, but unfortunately also has definite limits - it is not very good at looking after the poor, the environment, the long-term and the infrastructure and national strategic concerns such as self-reliance and external debt, all of which are of crucial relevance to the transport system. Hence, the visible hand of government and the people must complement the invisible hand of the market.

In conclusion, both short-term low-cost measures to attract political decision-makers with short time-horizons and long-term measures have been mentioned. The short-term measures consist mainly of better maintenance, better driving practices, optimal routing of buses, dedicated routes.

Poudenx (2008) offered a brief journey through twelve major cities with various policies in place to curb private vehicle use and assesses their success in term of energy consumption and greenhouse gas emission. Every region reviewed including Singapore is experiencing increase in energy use, greenhouse gas emissions and/or private vehicle ownership. In Europe, several regions improved transit quality and increased its ridership attracting non-motorized modes users instead of private vehicle users effectively increasing the total energy consumption. The author argues that policies aimed at reducing private vehicles use are failing because they do not incorporate the reality of human propensities for accessibility and comfort and they unsuccessfully try to attract customers toward services of lesser perceived quality. The demand for both accessibility and comfort will likely continue to grow with rising standards of living and will be met regardless of the environmental impact. Instead of attempting to constrain private vehicle use, the author suggests raising the competitiveness of alternate modes by investing in more attractive environments for non-motorized modes and designing transit systems actually capable of competing with private vehicles in term of perceived service quality while offering improved environmental performances.

Building on the legacy of historic greenway planning in the U.S., several new initiatives have been taking shape and gaining recognition in the past decade. One is 'Green Infrastructure' planning which is a 'must have' inter-connected system of green spaces. Walmsley (2006) is 'Smart Conservation'—the counterpoint of another planning initiative that preceded it known as 'Smart Growth'. This is the establishment of critical green corridors that should be preserved and maintained for predominantly ecological functions, in advance of or in conjunction with new development. 'New Urbanism' has focused on bringing order and coherence to escalating 'Edge Cities' on the urban fringe, based on walkable, mixed-use towns, villages and neighborhoods with integrated open-space systems. Transit-Oriented Developments (TOD) are transportation plans for accommodating regional growth around clustered 'pedestrian pockets' linked by transit systems. Both New Urbanism and TOD have applied similar principles to 'brown sites' and declining city neighborhoods. All these initiatives are different aspects of the greenway movement, expressing its many possibilities, enriching its original concepts, enlarging its credibility—if need be—and emphasizing its importance for and relevance to current issues of sustainability and 'green' planning and design. Walmsley (2006), a teacher/practitioner, discusses recent U.S. greenway examples at site, metropolitan and regional scales for which he has been the principal planner/designer or a consultant, and compares New Urbanism and TOD methodologies and approaches to established greenway-planning practices and the premises of Smart Conservation.

Vold (2005) described and applied a comprehensive framework to derive optimal and acceptable land use and transport strategies. The framework includes a constrained optimization algorithm that approximates and maximizes an objective function with respect to available land use and transport instruments and constraints based on Greater Oslo. As the results, they clarified that increasing fuel tax makes people more trip number of public modes and less passenger car use. Available instruments are toll ring charges, public transport frequency and a discrete land use instrument. Constraints represent acceptable levels on the available instruments, and acceptable levels on equity between geographical zones, accident cost reductions and the financial balance of the actual strategy. Strategies are found in situations with increased and reduced fuel taxes, and the direct and indirect land use and transport effects of the optimal strategies are assessed. The author suggest that increasing fuel tax is good for car sale or government's revenues, however the shorten the average trip length and increase of public modal share. In addition, increasing fuel tax has an effect on saving or trip time. Finally, it is linked to centralization of urban structure so that it contributes to restrain the CO_2 emission.

A forecast of transport activity, energy consumption and carbon dioxide emissions from transportation, carried out under 'business as usual' economic assumptions, is presented for the 10 countries of Central and Eastern Europe that have acquired the status of 'accession countries' to the European Union. Energy demand is projected under considerations of the dynamic evolution of transport modes and their use, the evolution of automotive fuel prices, which are assumed to gradually converge with Western European price levels within the current decade, and assumptions on efficiency improvements in all transport modes according to current technological trends and European regulations. Zachariadis and Kouvaritakis (2003) resulted, showing transportation energy demand to double and CO_2 emissions to be 70% higher in 2030 compared to 2000, are compared with other published forecasts and discussed with a view to potential future energy and environmental impacts in these countries, outlining major policy implications.

Cullinane (2003) argues that there are lessons to be learned from the Hong Kong situation, and that it is transport policies that are responsible for the low car-dependency levels rather than population density. He asserts that density is undeniably important in determining the level of car dependency, density alone is not sufficient to explain the low levels of car ownership in Hong Kong. Strict controls on parking and the high costs of motoring together with the prevalence of convenient and cheap public transport are policies which have been purposely implemented by the Hong Kong government to suppress the demand for private transport.

Meanwhile, energy consumption can be changed according the definition of the districts even located in same city. Parshall et al. (2010) demonstrated that the ability of Vulcan to measure energy consumption in urban areas. And they found that between 37% and 86% of direct fuel consumption in buildings and industry and between 37% and 77% of on-road gasoline and diesel consumption occurs in urban areas. In addition, they suggested that a county-based definition of urban is preferable to other common definitions. Urban counties, account for 37% of direct energy consumption, or 50% if mixed urban counties are included. Therefore, a county-based definition of urban can also improve estimates of per-capita consumption.

2.7 Conclusion of literature survey

The widespread study on transportation energy consumption covers analysis related to urban structure, travel behavior, economical factors, rail transit, urban-transport policies. They are mainly comparative study on its statistical indicators and data, its interaction with social economy, travel characteristics, urban density and so on. Mostly, they are targeting macroscopic range. On the basis of these researches, the current study should pay attention to the following aspects:

(1) Study on the comparative analysis based on objective statistic data and indicator. This research addresses Person Trip (PT) data and comprehensive statistical data on urban-transport in various cities of the world. Since comparative research utilizing a database on a worldwide scale in not yet established, methods to ensure the comparability of indicators as well as data attainability should be ensured.

(2) Certain comparable conditions, such as the load of transportation energy consumption, are required in the comparison of characters on transportation energy consumption.

(3) Study on the factors influencing transportation energy consumption as well as the sensitivity. Affected by different size groups, in the macro (urban) and micro (individual) level, transportation energy consumption should be studied in different collective groups.

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CHAPTER 3

Development of estimation method for transportation energy consumption and building a database on travel characteristics in the world

3.1 Overview of this chapter

Environmental issues, especially CO_2 emissions from the transportation sector, are a growing concern. Increasing energy consumption and emissions from automobiles are the two main contributors. In most developed countries, policy makers and urban planners accept the point of view that increasing urban density is expected to lead to decreasing energy consumption as a solution for transportation energy problem. For this reason, many European countries promote the concept of the compact city on the basis of environmental arguments. The concept that increasing urban density will decrease energy consumption is derived from the findings of Newman and Kenworthy's research (1989a, 1989b) which demonstrated a negative correlation between urban density and transportation energy consumption. Research related to transportation energy consumption, urban characteristics, and travel behaviors in high demand. Thus, a systematic method to provide reliable and objective data is needed. However, systematization of data is not trivial, and must be executed so that the data can follow research trends based on social, environmental, and technological changes. Although numerous systematization methods to estimate transportation energy consumption with regard to individual travel behaviors exist, there are sometime differences in the results regarding transportation energy consumption between many of systematization methods in the world. Therefore, a unified estimation method is necessary to estimate travel behaviors applying one standard in the field of comparative analysis for urban sustainability.

In this chapter, I developed revised estimation method for transportation energy consumption considering individual travel behaviors by private motorized modes. And also, I built a database on travel characteristics in the world targeting Asia, Europe, USA and developing countries. Here, it is suggested that improvement of conventional estimation method on transportation energy consumption is important for understanding individual travel characteristics based on household. Since conventional method on estimating transportation energy consumption cannot obtain information about the type of vehicle used in travel and individual travel behaviors on person level. Therefore, this research is focused on individual travel characteristics with Person Trip (PT) data.

In addition, I conduct comparative analysis on the relationship between urban density and travel characteristics for grasping the causal relationship of them.

3.2 Data in this research

The important drawback in using data in the world for comparison analysis lays in the unreliability of the data collection process. Even a UN bureaucracy hounding urban planners in the nations of the world to send their data on the appropriate forms sometime cannot guarantee that they used the same definition of what is 'urban' or what is a 'passenger trip' (Newman and Kenworthy, 1999). Other researchers have reached the conclusion that international urban comparisons can be used to develop policy. Thomson's "Great Cities and their Traffic (1977)" have made major contributions to urban policy. However, they tend to look at each city's data in isolation to seek a general pattern but only make qualitative comparisons between cities (Newman and Kenworthy, 1999). Other urban studies like those examining the changing structure of European cities or the environmental characteristics of US cities have standardized data collection but in these cases the authors are not examining transport and land use.

Meanwhile, Hass-Klau, (1985) also pointed out the difficulty on unifying the data in the world scale. He mentioned that the important obstacle in international analysis is lack of good and reliable urban data in his book "Can Rail Save the City" comparing British and German cities in some aspects of transport and land use with some data indicating what can be done in international study.

In general, it is rare for a city to have a central source of data on land use and travel patterns- they are scattered through various planning and transport agencies, often at different levels of government. In this context, I tried to find a more consistent and reliable set of data as soon as possible to provide insight into the question of automobile dependence through the contact with research institutes or public organizations which officially recognized.

As mention above chapters, transportation energy consumption is a strong reflection of how much dependence of private passenger vehicles there is in a city. On the other hand, there are many objectives in studying cities and collecting data on transportation and urban structure and also so many relationships between the social, economic and environmental aspects of urban life that are determined by the city's transport patterns and how the city is shaped. Therefore, there are many aspects of urban policy that lie behind this study all of which have a connection to the major topic. It is "*how we can reduce automobile dependence in cities*". And, the first step on collecting data is grasping the characteristics of travel behaviors of person at the individual level. This is the major reason why I focused on utilizing the Person Trip data in the current research.

In this research, the Person Trip data is mainly used for understanding characteristics of travel behaviors on person level. I collected Person Trip data of the cities in Japan, Korea, USA, Developing countries, Europe though the research institutes in the world.

The Person Trip data is disaggregated data on individual characteristics. The economic and social activities in city are made up by "*person*". And "*person*" who lives in urban and rural areas generates travel characteristics. The Person Trip data is used primarily for gaining a better understanding of travel behavior. The data enable to assess program initiatives, review programs and policies, study current mobility issues, and plan for the future. The Person Trip is a tool in the urban transportation planning process; it provides data on personal travel behavior, trends in travel over time, trip generation rates, national data to use as a benchmark in reviewing local data, and data for various other planning and modeling applications.

The transportation research community, including academics, consultants and government, use the Person Trip data extensively to examine:

Table 3-1 Utilization of Person Trip data

Major features
✓ *Travel behavior of the individual from household level*
✓ *The characteristics of travel, such as trip chaining, use of the various modes, amount and purpose of travel by time of day and day of week, vehicle occupancy, and a host of other attributes*
✓ *The relationship between demographics and travel*
✓ *The public's perceptions of the transportation system*

People in various fields outside of transportation use the Person Trip data to connect the role of transportation with other aspects of our lives. Especially, The Person Trip data is utilized in various fields on urban planning, traffic management. In addition, we can obtain the information related to individual travel behaviors in detail on the actual condition of traffic situation by utilizing the Person Trip data. The application fields of the Person Trip are introduced below Table 3-6. The official name of Person Trip data is different according to region in the world.

Table 3-2 Application fields of Person Trip data

Purpose	Project
• For grasping traffic situation and demand as a preliminary data of various projects	• A comprehensive planning of urban-traffic in prefecture of urban level • A master plan on urban development
• For appropriating a urban-traffic plan • For appropriating urban-traffic policies	• Initiatives on comprehensive urban transportation system • Road network planning, urban rail planning • New transportation planning, such as Tram, Monorail, Bus and so on. • TDM (Transit Development Management) • Plans on Station square and Bicycle-parking • Transportation planning related to development district in large-scale
• For drawing up report on urban transport plan and policies	• A report on the validity of the various planning and policy

However, the contents and composition of Person Trip is analogous with countries. The official name of Person Trip data or statistical data on travel behaviors in the current research are listed in Table 3-3 below.

Table 3-3 Person Trip data in the world

Nation	year	The name of "*Person Trip data*" in each country
Japan	2005	*The Nationwide Person Trip Survey* (2005)
Korea	2005	*Household Travel Survey* (Transport Database, 2005), (Inchon. Suwon. Sungnam (2006))
USA	2001	*National Household Travel Survey* (NHTS), Federal Highway Administration (FHWA)
Europe	2001	"*Mobility in Cities Database*" of UITP- International Association of Public Transport) In the case of European area, an aggregated data was utilized in the current research due to the limit of collecting data. "Mobility in Cities Database" is also an aggregated data on the characteristics of urban-transportation and mobility.
Developing Countries	1996~ 2005	*Person Trip Survey*, Japan International Cooperation Agency (JICA) 15cities in Developing countries are listed in Table in *Notes* at the end of CHAPTER 3.

3.3 Target cities in this research

Comparative analyses of cities around the world are rare, mainly due to difficulty collecting data. The most obvious and high profile example of comparative analysis of cities worldwide is a great achievement of Newman and Kenworhty, (1989a). They made an important contribution to understanding the relationship between travel characteristics, transportation energy consumption, and urban density, which elucidated as urban structure, with targeting 32 metropolitan areas in Europe, North America, Australia and Asia. The variations in per capita car use, transportation energy consumption and public transport use identified in their research were found to relate very closely to some major land use and transportation infrastructure indicators (eg. density of population and jobs, CBD parking supply, road supply etc.) As a result, they could offer some new explanations for the specific differences in automobile dependence and gasoline consumption between the metropolitan cities in the world. Especially, their graph about the inverse relationship between urban density and energy consumption for transport has become world famous. In this way, the study on urban-travel patterns has a long history in the field of transportation energy consumption. Nonetheless, most studies have considered only single metropolitan areas, regions or countries for analysis. As a consequence, few studies target international samples and within group, and most studies are constructed as limited-analysis derived from different national or local studies. In this context, I learned the drawback on studying cities in international level, and I needed to make plan to consider many metropolitan areas in the world. Thus, the data in this research were collected from 119 metropolitan areas in 38 countries. I tried to collect many target cities in the world as soon as possible.

The data was originally collected by research institutes around the world (The official names of the institutes are listed in the Notes after conclusions). Target cities in this study were defined as a metropolitan area with a minimum population of 800,000 to ensure that cities and traffic characters of metropolitan areas with similar population capacities were compared. And a city in which has features on major metropolitan area such as Tripoli is considered for target city even though the population is less than 800,000.

In this research, it should be noticed that the 14 cities in the developing countries are considered in analysis. Since, cities in the developing countries are today facing huge population growth and the accompanying growth in travel. They are struggling to keep up with these changes and to introduce sustainable urban transport policies. Individual mobility in cities in the developing countries is generally lower than in other regions of the world. However, these cities are characterized by strong growth in car ownership or private motorized modes. Although level of income is low, owning a car is often seen as a model of social success and this tends to boost growth in car ownership. Therefore, it is possible to mention that motorization of the cities in the developing countries is rapidly now in progress. In this context, these cities are useful with study for grasping the travel patterns in initial status of motorization.

The basic standard for selecting target cities is population. For this, statistical data generally on estimated population by *Population and Housing Census* in the world was collected.

Figure 3-1 Target cities in this research

Source of background map of the world: http://www.world-geographics.com

Table 3-4 Target cities in Asia and Oceania region

Asia and Oceania				
Nation	**City**	**Year**	**Population**	**Description**
Japan	Tokyo	2005	8,499,697	The 14 cities having more than 800,000 population which carried out *Population and Housing Census by ministry of Public Management Japan*(2005)
	Yokohama		3,579,628	
	Osaka		2,628,811	
	Nagoya		2,215,062	
	Sapporo		1,880,863	
	Kobe		1,525,393	
	Kyoto		1,474,811	
	Fukuoka		1,401,279	
	Kawasaki		1,327,011	
	Saitama		1,176,314	
	Hiroshima		1,154,391	
	Sendai		1,025,098	
	Kitakyushu		993,525	
	Chiba		924,319	
Korea	Seoul	2005	10,297,004	The 9 cities having more than 800,000 population which carried out *Population and Housing Census (2005) by ministry of Statistics Korea*
	Pusan		3,657,840	
	Daegu		2,525,836	
	Inchon		2,632,178	
	Kwangju		1,408,106	
	Daejeon		1,462,535	
	Ulsan		1,095,105	
	Suwon		1,046,591	
	Sungnam		992,758	
Singapore	Singapore	2001	3,320,000	Refer to "***footnote * Table in Notes at the end of CHAPTER 3***" for detail description
China	Hong Kong	2001	6,720,000	
Arab Emirates	Dubai	2001	910,000	
Australia	Melbourne	2001	3,370,000	
	Total: 27 cities			

And for the case that I could not get the Census data, I quoted official population data which announced by research institute around. Figure 3-1 shows the target cities in this research and the target cities are organized by a region (Asia and Oceania, Europe, USA, Developing countries) through Table 3-4 to Table 3-7.

First, Table 3-4 shows the 27 cities in Asia and Oceania regions. In deciding to carry out an international comparison of cities, the most difficult question was "What cities do we actually want to study?". There are various explanations related to city—Metropolitan area, Urban area, Inner area, Outer area and so on. Therefore, defining the spatial range for analysis was a big obstacle in the first stage of the current research.

As a result of survey on data in the world, it was obvious that data is generally composed with limited spatial range in administrative. It was not difficult work to unify the spatial range on analysis from aspect of demography and travel pattern. The most appropriate and meaningful way of defining a metropolitan area is to take what can be termed the full functional urban region. This is usually a large, fairly contiguous built up area in which may transcend any number of political or administrative boundaries such as those of Cities and States, but in which functionally acts as a single and unified region.

Table 3-5 Target cities in USA

USA				
Nation	**City**	**Year**	**Population**	**Description**
USA	New York	2001	17,775,000	The 46 cities having more than 800,000 population which carried out *Population and Housing Census (2001) by Bureau of the Census in USA*
	Los Angeles-Long Beach-Santa Ana		12,540,000	
	Chicago		8,140,000	
	Philadelphia		5,300,000	
	Dallas-Fort Worth Arlington		4,445,000	
	Miami-Fort Lauderdale		5,330,000	
	Washington		4,280,000	
	Houston		3,790,000	
	Detroit		4,055,000	
	Boston		4,075,000	
	Atlanta		4,170,000	
	San Francisco-Oakland		4,140,000	
	Phoenix		3,270,000	
	Seattle		3,005,000	
	Minneapolis-St. Paul		2,520,000	
	San Diego		2,905,000	
	St. Louis		2,105,000	
	Baltimore		2,315,000	
	Pittsburgh		1,800,000	
	Tampa-St. Petersburg		2,250,000	
	Denver Aurora		2,090,000	
	Cleveland		1,790,000	
	Cincinnati		1,620,000	
	Portland		1,730,000	
	Kansas City		1,500,000	
	Sacramento		1,750,000	
	San Antonio		1,360,000	
	Orlando		1,360,000	
	Columbus		1,195,000	
	Providence		1,245,000	
	Norfolk- VA Beach Newport News		1,540,000	
	Indianapolis		1,035,000	
	Milwaukee		1,460,000	
	Charlotte		860,000	
	New Orleans		1,090,000	
	Nashville-Davidson		990,000	
	Austin		855,000	
	Memphis		1,020,000	
	Buffalo-Niagara Falls		1,130,000	
	Louisville		905,000	
	Hartford		890,000	
	Jacksonville		990,000	
	Oklahoma City		850,000	
	Rochester		1,041,000	
	Salt Lake City		970,000	
	Honolulu		876,000	
	Total: 46 cities			

In this way, I focused on the population scale of city for defining a metropolitan area. As a good example, the case of Japan, a city designated by government ordinance (*Seirei shitei toshi* in Japanese) is a major Japanese city that delegated many of the functions normally performed by prefectural governments in fields such as public, social and urban planning.

And, the designated cities before 2005 are 14 cities that have a population greater than 800,000. The approach in the current research has always been to try to define each metropolitan area according to its full functional urban region. Therefore, I decided to follow the standard of Japanese designated cities as a full functional urban region.

In this context, target cities in this study were defined as a metropolitan area with a minimum population of 800,000 to ensure that cities and traffic characters of metropolitan areas with similar population capacities were compared.

Next, Table 3-5 shows the 46 cities in USA targeting in the current research. The high cost of gasoline in the US has made automobile fuel consumption a significant issue in transportation energy security and the national economy. The US consumed 20.8 million barrels of oil a day in 2005, accounting for approximately 25% of the world's daily consumption; roughly two-thirds of the oil consumed in the US can be attributed to the transportation sectors (Young et al., 2007). Generally defined as decentralized land use patterns characterized by low population densities and auto-oriented design schemes, urban sprawl has been demonstrated to greatly elevate the cost of urban services by increasing the distance between new development and the established infrastructure of roads, sewer lines, and transit systems (Burchell et al., 2002). Especially, large US metropolitan areas have these features and many researches targeting US metropolitan areas have demonstrated an association between various attributes of urban-transport and energy consumption of transport (Stone, 2008). I am focusing on urban transportation energy consumption since this is the greatest challenge and an area in which policies adopted in the near future will have a crucial impact on long term energy consumption. Therefore, I targeted 46 large US metropolitan regions and discussed the role of urban density and its characteristics on travel behaviors.

Table 3-6 below reveals the 31 target cities in European region. In the case of European cities, there was a limit to collect Person Trip data of every country in Europe. Fortunately, however, International Association of Public Transport (UITP) conducted a survey for collecting annual statistical data—*Mobility in cities (MCD), 2001*—on demography and urban mobility of various areas in Europe. The database by UITP is taken from annual statistics refer to 2001. And, it offers 120 aggregated indicators in the field on metropolitan areas on urban structure, demography, transport features including private motorized modes, public modes and Non-motorized modes (Bicycling and walking), development of infrastructure, and energy consumption. Therefore, most data in European region are obtained from the MCD provided by the UITP. Even though the database of UITP is aggregated one, the data from UITP is based on the disaggregated data in each European country so that I could utilize it in analysis with unified standard by considering the properties of database.

Cities in European region are import samples in this research. Because rail transit in European region experienced a rapid decline at the second half of the 20th century, at the same time, as privatization of rail operation gains pace also act to promote the use of railway system (Brons et al., 2009). According to Poudenx (2008), several regions in Europe improved rail transit quality and increased its ridership attracting Non-motorized modes users instead of private vehicle users effectively increasing the total transportation energy consumption. First, the service which explained with expanding more lines, faster mode and higher frequency has been improved. The quality was also improved with more reliable schedules, better connections and better services such as park-and-ride of bike-and-ride facilities as well as better weather protection at stops and more attractive stations. Finally, the fares themselves also have been reduced to attract more customers.

Therefore, European cities are good samples for understanding the results of the positive side and negative side on efforts related to promoting the use of rail transit. If there are successful examples in European region, it can be used as a benchmark for various initiatives and applications.

Table 3-6 Target cities in Europe

Europe				
Nation	**City**	**Year**	**Population**	**Description**
Germany	Berlin	2001	3,390,000	The 33 cities having more than 800,000 population which targeted in *"Mobility in Cities Database" of International Association of Public Transport(UITP) in 2001* (Krakow is exception due to the characteristics of major metropolitan area in Poland)
	Stuttgart		2,380,000	
	Munich		1,250,000	
Austria	Vienna		1,550,000	
Belgium	Brussels		964,000	
Denmark	Copenhagen		1,810,000	
Spain	Madrid		5,420,000	
	Barcelona		4,390,000	
	Valencia		1,570,000	
	Bilbao		1,120,000	
	Seville		1,120,000	
Finland	Helsinki		969,000	
France	Paris		11,100,000	
	Lyon		1,180,000	
	Lille		1,100,000	
Greece	Athens		3,900,000	
Hungary	Budapest		1,760,000	
Italy	Rome		2,810,000	
	Turin		1,470,000	
Norway	Oslo		981,000	
Netherlands	Rotterdam		1,180,000	
	Amsterdam		850,000	
Poland	Warsaw		1,690,000	
Portugal	Lisbon		2,680,000	
Czech Republic	Prague		1,160,000	
UK	London		7,170,000	
	Manchester		2,510,000	
	Glasgow		2,100,000	
	Newcastle		1,080,000	
Russia	Moscow		11,400,000	
Switzerland	Zurich		809,000	
	Total: 31 cities			

Last, Table 3-7 shows the 15 cities of 14 developing countries. As mention above, the cities in the developing countries are useful with understanding the travel behaviors in initial state of motorization. These developing cities have unique properties on urban-transport status.

The space taken up by private motorized modes has a major impact on the operation of cities. Road congestion reduces economic productivity and aggravates public transport problems. Air pollution seriously increases, affecting public health. The growing proportion of private motorized modes in the developing cities excludes people without sufficient means buying only a vehicle (Varnaison-Revolle et al., 2007). Therefore, the cities in the developing countries are sucked into a spiral of unsustainable development when it comes to urban mobility.

As mentioned, they include the rapid pace of motorization, conditions of local demand that far exceed the capacity of facilities, the incompatibility of urban structure with increased motorization,

Table 3-7 Target cities in Developing countries

<table>
<tr><th colspan="5">Developing countries</th></tr>
<tr><th>Nation</th><th>City</th><th>Year</th><th>Population</th><th>Description</th></tr>
<tr><td>Peru</td><td>Lima</td><td>2003</td><td>8,043,000</td><td rowspan="15">The 14 cities in developing countries more than 800,000 population which carried out Population Census and Urban- Transport master plans by Japan International Cooperation Agency (JICA)

(Tripoli is exception due to the characteristics of major metropolitan area in Lebanon)

Refer to “footnote * * Table in Notes at the end of CHAPTER 3” for detail description</td></tr>
<tr><td>Brazil</td><td>Sao Paulo</td><td>2001</td><td>18,300,000</td></tr>
<tr><td>Malaysia</td><td>Kuala Lumpur</td><td>1997</td><td>1,390,800</td></tr>
<tr><td>Lebanon</td><td>Tripoli</td><td>2000</td><td>330,900</td></tr>
<tr><td>China</td><td>Chengdu</td><td>2000</td><td>3,090,000</td></tr>
<tr><td>Egypt</td><td>Cairo</td><td>2001</td><td>14,400,000</td></tr>
<tr><td rowspan="2">Vietnam</td><td>Ho Chi Minh</td><td>2002</td><td>7,653,000</td></tr>
<tr><td>Hanoi</td><td>2005</td><td>3,183,000</td></tr>
<tr><td>Syria</td><td>Damascus</td><td>1998</td><td>3,078,190</td></tr>
<tr><td>Philippines</td><td>Manila</td><td>1997</td><td>9,454,000</td></tr>
<tr><td>Indonesia</td><td>Jakarta</td><td>2000</td><td>8,792,000</td></tr>
<tr><td>Nicaragua</td><td>Managua</td><td>1998</td><td>1,800,000</td></tr>
<tr><td>Cambodia</td><td>Phnom Penh</td><td>2000</td><td>1,242,241</td></tr>
<tr><td>Kenya</td><td>Nairobi</td><td>2004</td><td>4,041,900</td></tr>
<tr><td>Romania</td><td>Bucharest</td><td>1998</td><td>2,150,000</td></tr>
<tr><td></td><td colspan="3">Total: 15 cities</td><td></td></tr>
</table>

a stronger transport-land use relationship than in developed cities, lack of adequate road maintenance and limited agreement among responsible officials as to appropriate forms of approach to the problem (Gakenheimer, 1999). However, only a few studies toward solving the problem in developing world.

Therefore, this research considers developing cities to make contribute to understanding the characteristics on urban-transport of those and I tried to collect the Person Trip data as much as possible by contacting with Japan International Cooperation Agency (JICA).

3.4 Development of estimation method on transportation energy consumption

3.4.1 Focusing Private Motorized Modes (PMM) and the definition of trip

In describing motorization, the field of urban-transport and environment involve quite big and wide range. Therefore, this research cannot deal with all of problems related to motorization. For example, aviation and maritime transport also emit harmful exhaust gases into the atmosphere, and in some limited regions also have serious environmental problems attributed to driving vibration or noise due to the railway system. In addition, global environmental problem could be serious environmental issue, however, for people in the developing countries it is not in too much trouble. In this context, it should be noted that I only focus on transportation term.

From the viewpoint that reduction of transportation energy consumption can be obtained by controlling the individual modes of transportation appropriately, the current research extracted the data for trips made by Private Motorized Modes (PMM: passenger car, motorcycle, and taxi).

The more economic level has developed, the more passenger car ownership has been increased. Automobile is an indispensable mean to urban life and urban structure also has been changed to the form adopted itself to automobile use (Nakamura et al., 2004). On the other hand, motorization has played a role as a lubricant on easy mobility and flexible selecting the residential area or working place by offering door-to-door accessibility.

However, automobile dependence has occurred serious novel social problems. In the urban regions, road congestion is remarkably shown in many countries, and it is said that increasing a substantial socioeconomic loss, emotional and physical burden are attributed to serious congestion in urban region. According to the report of MLITT (2001), annual economic loss by road congestion in Tokyo can be estimated to be 37.1 million yen per 1 kilometer of road, and the total annual loss in Japan might be more or less 12 trillion yen.

In recent years, the range of individual travel behavior is expanding with the progress of car ownership, and this parallels economic development in cities. Urban density is also changing to suburbanization as the urban population is moving outside of city. Moreover, this movement is linked to increases in transportation energy consumption, and has caused serious urban problems such as air pollution and excessive energy consumption. As Parshall et al. (2010) investigated, the usage of on-road gasoline and diesel in urban areas of the Unite State is as much as 77% of total fuel consumption in the US, and fuel consumption and CO_2 emissions from gasoline and diesel in urban areas tend to be higher than that of buildings and industries.

In this way, automobile dependence is associated with our urban life style, and changing travel pattern in a city. Consequently, the side effects of motorization have come to the surface, suggesting that improvements in individual mobility by the economic development and the progression of motorization are maintaining suburbanization, where broadens low density areas around the urban area regardless of nation (Eom and Schipper, 2010).

Because of strong connection between increase of trip length and transportation energy consumption (Choi et al., 2011), it is important to guide travel behaviors of private motorized modes and develop urban areas as sustainable space. Furthermore, the increase of trip length as a result of suburbanization is directly linked to increases in transportation energy consumption. This makes it difficult to say that the policies for reducing automobile use and transportation energy reduction have been successful.

Hence, freight traffic, which it is difficult to determine the supplying and consumption districts for fuel, was excluded from this research. In addition, the trip mode used in trips with the longest trip time in a complete trip was treated as the representative mode for the trip. Furthermore, extracted trips below 4 km/h on the representative mode were excluded from target trip as walking and the maximum trip speed is set as 100km/h. This research also restricted trip length to within 150 km/trip for considering the maximum diameter of the targeted urban area. Next, in the case of counting passenger numbers on PMM trips on Japanese PT, passenger number cells are sometimes left blank or "N/A," despite the presence of a driver. In this case PT information was counted as "1" for the driver. Finally, the trips are extracted from the condition that trips made with at least one extremity (origin and/or destination) inside the urban area and based on the household being inside the urban area. However, US cities are only considered household constraint due to the limitation on data contents of PT data from NHTS (National Household Travel Survey).

In this research, trips that obey the above constraint conditions were extracted from the total trips made within the target city and used for estimation of transportation energy consumption.

3.4.2 Conventional estimation methods on transportation energy consumption

The most common method to estimate transportation energy consumption is to measure the total consumption of fuel in a city by applying statistical data of the total amount of fuel sold, and then converting the total consumed sold fuel into energy per unit amount of fuel (Kenworthy and Laube, 1999: Morimoto and Koike, 1995).It is difficult to determine the supplying and consumption districts for fuel (Matsuhashi et al., 2004).

The conventional method can simply estimate total energy consumption in a city level which is suitable for assessment of fuel consumption measures. However, it cannot obtain information about the type of vehicle used in travel and individual travel behaviors on person level. This research is focused on a point of view which controlling private motorized modes (taxies and motorcycles as well as passenger car, including light car, small van, pickup truck, SUV) can be linked to controlling transportation energy consumption. Private motorized modes are based on household so that they could be always influenced by the urban structure that represented by the dispersion degree of a residential area. Therefore this information (the type of vehicle, individual travel behaviors on person level which affected by urban density) is important to understand the factors affecting transportation energy consumption. In other words, energy consumption in this research means a result which can be controlled. Meanwhile, logistics transportation is not considered in this analysis because it is not based on household and it is difficult to understand travel characteristics of logistics from PT data.

Henceforth, policymakers need to grasp quantitatively what factors affect transportation energy consumption in order to establish a strategy on urban planning for reducing transportation energy consumption. For that, it is necessary to not only estimate transportation energy consumption of the whole city but also to understand the relationship between individual travel behaviors and energy consumption. In that sense, the improved method in this research is useful to illuminate the characteristics of individuals' travel behaviors related to transportation energy consumption.

3.4.3 Calculation methods for travel characteristics in this research

The latter half of this chapter describes the procedures used to calculate the average trip length, average vehicle speed, number of daily trips, and modal share of private motorized modes in a city. Since this research employs Person Trip data, various data regarding different properties of travel behavior can be extracted.. Table 3-9 shows the calculation method for each aspect of travel behavior. To estimate transportation energy consumption, four main travel characteristics were considered: trip length, trip speed, daily trip number, and modal share of private motorized modes, as mentioned in the previous chapter. These data on travel characteristics were calculated from person trip data released by public institutes around the world. However, the data fields of the person trip data differ by country.

It should be noted that the calculation method of travel behavior in Table 3-9 differs slightly by country and depends on the how the person trip data was configured. Moreover, due to the limitations in the data from European cities and some Korean cities, travel characteristics were estimated throughout the whole urban area using the cities average of trip values on travel behavior.

3.4.4 Revised estimation method on transportation energy consumption

The most common method to estimate transportation energy consumption is to measure the total consumption of fuel in a city by applying statistical data of the total amount of fuel sold, and then converting the total consumed sold fuel into energy per unit amount of fuel (Kenworhty et al., 1999; Morimoto, 2002). In addition, it is difficult to determine the supplying and consumption districts for fuel (Matsuhashi et al., 2004). Alternatively, in Japan, as an estimation method of transportation energy consumption, the integrating energy intensity and trip length is generally used. Although the former is suitable for grasping a discharge of the total amount or total evaluation of the measure against fuel, there are limitations regarding the vehicle type and the evaluation of travel behavior in an independent trip (Morimoto and Koike, 1995). Since the latter may differ in the estimation value of energy intensity with various statistical materials, comparison between cities not straightfoward.

This research exploits the data on traffic behavior for every individual trip based on PT data and the formula for fuel efficiency of a gasoline vehicle considering the travel speed defined from measurement of the "Sdsdynamo" experiment conducted by the ministry of the environment in Japan. From this data and estimation formula, the transportation energy consumption is calculated using (Eq.3-1).

$$E_k = \left(\frac{\sum_i^{n^k} T_i \cdot I_i \times 365}{O_k^r} \right) / P_k \qquad \textbf{(Eq. 3-1)}$$

E_k = Annual transportation energy consumption by private motorized modes per capita in city k (MJ per capita: All of vehicle in the current research is assumed as gasoline vehicles because of the limitation on classification in the fuel type of vehicle from PT data; refer to *Notes* (6) at the end of CHAPTER 3)

T_i = Transportation energy consumption by private motorized modes in single trip i (MJ) (i=1,..., n^k; n^k : the number of trip sample in city k)

P_k = Urban population in city k

I_i = Expansion coefficient of each trip i

(The ratio between total population in zone X and the number of sample in zone X, X=1,...., m^k; m^k is the number of zone in city k)

O_k^r= Average occupancy of mode r in city k

Table 3-8 Definition of data in this research

No	Indicator	Unit	Definition of data	(Num. of data source)
1	*Urban City*	N/A	Boundaries of a metropolitan area are set based on different factors. Search for the most relevant area to study mobility, that is, an economic area where the bulk of daily home-work journeys occurs, which is sometimes referred to as the "labor catchment area".	Korea:(3), Japan: (3), Europe:(2), USA:(3), Developing countries:(3)
2	*Population*	inhabitants	Total number of residents in the urbanized area.	Korea:(2), Japan: (2), Europe:(2),USA:(2), Developing countries:(2),
3	*Urban Density*	Inhabitant /ha	Ratio between the population(Indicator 2) and urban surface area.	Korea:(2), Japan: (2), Europe:(2), USA:(2), Developing countries:(2),
4	*GRDP per capita*	$/ person	Ratio between the GRDP of the urbanized area and its population.	Korea:(4), Japan: (4), Europe:(2), USA:(5), Developing countries:(2),
5	*Passenger cars per thousand inhabitants*	vehicle/ 1000 inhabitants	Number of passenger cars in urbanized area includes all vehicles with three/four wheels or more used primarily for private transportation of persons, but does not include taxis or public transport vehicles. -Population figures used to compute the ratio is defined above (indicator 2).	Korea:(4), Japan: (4), Europe:(2), USA:(4), Developing countries:(2),
6	*Average distance of private motorized modes*	km/trip	With reference to trips defined by indicator 8, including automobiles, motorcycles, and taxis, the actual distance is sought, not a straight line distance. -In this case, trips extending beyond the urbanized area are considered.	Korea:(3), Japan: (3), Europe:(2), USA:(3), Developing countries:(3),
7	*Daily trips per capita*	Trip/ day/ person	Characterized as: -Trips made by persons over 5 years of age who reside in the urbanized area. -Trips with at least one extreme (origin and/or destination) inside the urbanized area. -All reasons for travel and all transport modes, motorized, or otherwise. -Trips on foot are included. -Trips made using several modes are counted as one trip and assigned to a "primary mode".	Korea:(3), Japan: (3), Europe:(2), USA:(3), Developing countries:(3),
8	*Percentage of private motorized trips*	%	Percentage of the total number of daily trips (Indicator 8) made by the private motorized modes (i.e., private cars, motorcycles, taxis).	Korea:(3), Japan: (3), Europe:(2), USA:(3), Developing countries:(3),
9	*Car occupancy*	Persons/ vehicle	The average passenger car occupancy rate is an annual rate estimated for the passenger cars over the metropolitan area's entire road network.	Korea:(3), Japan: (3), Europe:(2), USA:(3), Developing countries:(3),
10	*Annual transportation energy consumption*	MJ/ person	Evaluating value of annual transport energy consumption by private motorized vehicles and motorcycles per capita.	Korea:(4), Japan: (4), Europe:(2), USA:(4), Developing countries:(2),

Table 3-9 Calculation methods to explain travel characteristics data

Data on travel behavior	Applied cities (Num. of sample cities)	Equations	Data resources (Num. of data source)	Note
Trip length (km)	Korea (9) Developing countries(14)	$L_k = V_k \ (\sum_1^n (I_i^{r,k} \cdot D_i^{r,k}) / \sum_1^n I_i^{r,k})$	V_k: (4) V_k: (2), (3)	Suwon, and Sungnam in Korea followed the equation of Europe.
	Europe (31), Wealthy Asian (4)	L_k	(2)	
	Japan (14) USA (46)	$L_k = (\sum_1^n (I_i^{r,k} \cdot l_i^{r,k}) / \sum_1^n I_i^{r,k})$	(3)	
Vehicle speed (km/h)	Korea (9) Developing countries(14)	V_k	(4) (2)	N/A
	Europe (31), Wealthy Asian (4)	$V_k = L_k / D_k$	(2)	
	Japan (14) USA (46)	$V_k = (\sum_1^n (I_i^{r,k} \cdot l_i^{r,k}) / \sum_1^n I_i^{r,k}) / (\sum_1^n (I_i^{r,k} \cdot D_i^{r,k}) / \sum_1^n I_i^{r,k})$	(3)	
Number of daily trips (trips/day/ person)	Europe (31), Wealthy Asian (4)	T_k	(2)	Suwon, and Sungnam in Korea followed the equation of Europe.
	Korea (9), Japan (14), USA (46), Developing countries(14)	$T_k = \frac{\sum_1^n I_i^k}{Total\ population\ in\ city\ k}$	(3) (3) (3)	
Modal Share of PMM (Private passenger vehicle+ Motorcycle)	Europe (31), Wealthy Asian (4)	M_k^r	(3)	Private passenger vehicles, includes taxies
	Korea (9) Japan (14) USA (46), Developing countries(14)	$M_k^r = (\sum_1^n (I_i^{r,k}) / \sum_1^n I_i^k) \times 100$	(2) (3) (3)	
Average occupancy rate of mode r	Korea (9), Europe (31), Wealthy Asian (4) Developing countries(14)	O_k^r	(3) (2) (2)	N/A
	Japan (14), USA (46)	$O_k^r = \sum_1^n (O_i^{r,k} \cdot I_i^{r,k}) / \sum_1^n I_i^{r,k}$	(3)	

Note: k = Cities (k=1,...,119), i=Trip sample (i=1,..,n), l_i=Trip length of i, d_i=travel time of i, r=representative trip mode (r=A,B,C; A=PMM(Private Motorized Modes), B=PUB(Public modes), C=NMM(Non-Motorized Modes)), L_k=Average trip length in city k, V_k=Average vehicle speed in city k, $D_i^{r,k}$=Average travel time of trip i by mode r in city k, T_k=Average daily trip number in city k, M_k^r=Average modal share by mode r in city k, $I_i^{r,k}$=Expansion factor of trip i by mode r in city k, O_k^r= Average occupancy of mode r in city k

Moreover, in formula (Eq. 3-1), Transportation energy consumption by private motorized modes in single trip *i* can be calculated using (Eq. 3-2).

$$T_i = FC_{(V_i)} \cdot HV \cdot L_i \quad \textbf{(Eq. 3-2)}$$

HV = Average calorific value of gasoline (MJ/L)

$FC_{(V_i)}$ = Fuel efficiency of a vehicle on trip *i* at speed *v* (cc/km; Motorcycle is assumed to have a half the efficiency of a car and vehicle is assumed to be gasoline vehicle; Refer to *Notes* (7) at the end of CHAPTER 3)
L_i = Trip length of trip *i* (km)
V_i = Trip speed of trip *i* by private motorized modes (km/h)

However, in this research, private motorized modes are limited to passenger cars, taxi, and motorcycles. Fuel efficiency of private motorized modes on trip *i* at speed *v* is obtained using (Eq. 3-3) (Oshiro et al., 2001).

$$FC_{(V_i)} = [829.3/V_i] - 0.8572V_i + 0.007659{V_i}^2 + 64.09 \qquad \textbf{(Eq. 3-3)}$$

The model parameters in (Eq. 3-3) are inferred from the results of research conducted in Japanese research institute. However, the model parameters can be customized to country or vehicle type. The results in (Eq. 3-3) are based on the use of a passenger car. Eventually, the renewal estimation method becomes a function of vehicle speed in an individual trip. For cases where the PT data has insufficient trip information, the improved method is a form of (Eq. 3-1). For European cities and several Korean cities, travel characteristics such as average vehicle speed, average trip length, and modal share of private motorized modes, are representative values due to limitations in gathering world data. Therefore, I evaluated an alternative estimation method for cases lacking these data using (Eq. 3-4).

$$E_k = P_k \cdot G_k \cdot \gamma_k \cdot l_k \cdot e \qquad \textbf{(Eq. 3-4)}$$

E_k= Transport energy consumption in city k (MJ)
P_k= Population in city k (person)
G_k= Average daily trip number in city k (trip)
γ_k= Modal share of private motorized modes in city k (%)
l_k= Average trip length in city k (km/trip)
e= Intensity of energy consumption (MJ/person・km)

This is useful for estimating transportation energy consumption based on average trip length for private motorized modes per day, average number of daily trips in city *k*, modal share of the private motorized modes of transportation, and population in city *k*. Additionally, the average speed of the private motorized modes and intensity of heat combustion are multiplied to estimate fuel efficiency of vehicle.

If a city has its own PT data, the renewed estimation method is promising. However, when this model cannot be applied due to the lack of PT data, the alternative method can be improved by incorporating vehicle speed. This improvement is realized by changing the intensity factor *e* in (Eq. 3-4) into e_k. The estimation method for the factor *e* can be revised by

$$e_k = FC_{(V_k)} \cdot HV \qquad \textbf{(Eq. 3-5)}$$

e_k = Intensity of energy consumption of city k (MJ/person・km)
$FC_{(V_k)}$ = Fuel efficiency of a vehicle at average speed V_k (cc/km)
V_k = v_k = Average vehicle speed in city k (km/h)

Table 3-10 Database of transportation energy consumption in cities of the world (private motorized modes)

No	Nation	Urban	Population	Urban density	Average distance Private motorized Modes (km/trip)	Number of daily Trips	Private motorized modes (%)	Public modes (%)	Private car ownership (vehicles/ 1,000inhabitant)	Transport energy Consumption (MJ/person)
1	Korea	Seoul	10,297,004	170.1	13.2	2.42	24.7	36.2	215	2,438
2	Korea	Pusan	3,657,840	38.5	12.8	2.53	34.0	30.9	212	8,231
3	Korea	Daegu	2,525,836	28.6	12.1	2.54	38.5	19.5	269	7,714
4	Korea	Inchon	2,632,178	36.5	15.0	2.50	35.3	25.6	245	7,372
5	Korea	Kwangju	1,408,106	28.1	14.6	2.53	43.2	19.4	294	7,359
6	Korea	Daejeon	1,462,535	29.5	10.7	2.52	41.8	15.7	287	6,425
7	Korea	Ulsan	1,095,105	14.6	11.2	2.54	43.4	13.8	289	9,785
8	Korea	Suwon	1,046,591	86.2	13.3	2.66	43.9	21.1	276	9,781
9	Korea	Sungnam	992,758	70.1	11.4	2.77	43.1	34.3	263	8,613
10	Japan	Tokyo	8,499,697	146.1	13.9	2.09	14.5	33.4	345	3,548
11	Japan	Yokohama	3,579,628	108.4	12.1	2.01	25.8	32.4	287	5,304
12	Japan	Osaka	2,628,811	124.3	13.3	1.97	9.6	9.6	202	2,148
13	Japan	Nagoya	2,215,062	73.6	8.6	2.11	40.0	15.1	386	6,812
14	Japan	Sapporo	1,880,863	75.4	9.2	1.96	42.1	16.3	359	6,191
15	Japan	Kobe	1,525,393	76.1	13.1	1.97	21.7	9.7	265	4,238
16	Japan	Kyoto	1,474,811	98.3	9.9	1.92	20.9	7.8	256	3,397
17	Japan	Fukuoka	1,401,279	89.5	9.0	2.18	35.4	8.4	311	6,279
18	Japan	Kawasaki	1,327,011	104.5	10.6	1.95	18.9	38.4	239	3,305
19	Japan	Saitama	1,176,314	101.5	8.4	2.14	26.9	24.9	161	4,001
20	Japan	Hiroshima	1,154,391	73.2	10.9	2.14	40.0	9.5	320	7,524
21	Japan	Sendai	1,025,098	56.9	10.0	2.04	46.4	11.6	101	7,116
22	Japan	Kitakyushu	993,525	48.6	10.5	1.95	47.0	6.7	316	8,298
23	Japan	Chiba	924,319	71.8	9.1	2.04	30.8	25.2	352	4,892
24	Russia	Moscow	1,400,000	161.0	12.0	2.67	33.9	49.3	189	6,251
25	France	Paris	11,100,000	40.5	8.2	2.81	46.4	18.0	439	9,187
26	UK	London	7,170,000	54.9	9.0	2.65	50.2	18.8	343	9,560
27	Spain	Madrid	5,420,000	55.7	11.0	2.71	51.4	22.4	478	10,719
28	Spain	Barcelona	4,390,000	74.7	10.8	1.85	46.9	18.8	424	6,934
29	Greece	Athens	3,900,000	65.7	10.0	1.61	63.9	27.9	385	9,169
30	Germany	Berlin	2,930,000	54.7	8.3	3.05	39.3	24.6	328	7,874
31	Italy	Rome	2,810,000	62.6	12.0	2.19	56.2	20.2	689	12,156
32	Portugal	Lisbon	2,680,000	27.9	8.3	1.61	48.0	27.5	432	6,193
33	UK	Manchester	2,510,000	40.4	8.0	2.84	68.1	9.4	434	10,222
34	Germany	Stuttgart	2,380,000	35.3	11.0	3.28	58.9	11.0	566	13,514
35	UK	Glasgow	2,100,000	29.5	8.0	2.96	65.9	10.6	345	11,084
36	Denmark	Copenhagen	1,810,000	23.5	13.0	3.00	48.9	12.1	315	10,306
37	Hungary	Budapest	1,760,000	46.3	9.0	2.85	33.1	43.5	329	8,197
38	Poland	Warsaw	1,690,000	51.5	10.0	2.26	28.6	51.6	380	5,077
39	Spain	Valencia	1,550,000	50.2	11.5	2.09	41.3	12.4	466	7,965
40	Austria	Vienna	1,550,000	66.9	10.3	2.70	36.0	34.0	414	6,483
41	Italy	Turin	1,470,000	46.1	9.4	1.82	54.0	21.1	637	8,447
42	Germany	Munich	1,250,000	52.2	15.0	3.20	40.6	21.9	542	14,397
43	Netherlands	Rotterdam	1,180,000	41.4	9.0	2.74	48.3	9.7	356	9,428
44	France	Lyon	1,180,000	40.0	6.4	3.37	54.3	13.0	489	10,518
45	Czech Republic	Prague	1,160,000	44.0	8.0	3.71	35.6	43.3	536	7,706
46	Spain	Bilbao	1,120,000	51.9	14.9	1.95	35.4	16.0	392	6,942
47	Spain	Seville	1,120,000	51.1	8.0	1.85	48.0	10.4	406	6,670
48	France	Lille	1,100,000	55.0	5.4	3.59	63.2	6.1	413	10,754
49	UK	Newcastle	1,080,000	42.5	9.8	2.52	57.1	16.1	320	8,956
50	Norway	Oslo	981,000	6.1	9.0	3.18	59.1	15.4	418	10,908
51	Finland	Helsinki	969,000	44.0	8.8	3.10	44.0	27.0	361	7,851
52	Belgium	Brussels	964,000	73.6	10.1	2.82	58.9	13.6	497	11,828
53	Netherlands	Amsterdam	850,000	57.3	11.0	2.90	33.9	14.7	336	7,591
54	Switzerland	Zurich	809,000	44.5	11.8	3.18	46.4	23.0	495	11,013
55	USA	New York	18,490,029	14.5	12.9	3.36	59.9	8.1	460	12,931
56	USA	Los Angeles-Long Beach-Santa Ana	12,540,000	21.6	13.6	3.74	78.7	1.6	516	16,217
57	USA	Chicago	8,140,000	14.8	12.3	3.51	75.8	3.6	488	14,113
58	USA	Philadelphia	5,300,000	11.4	12.9	4.03	69.3	5.4	475	18,738
59	USA	Dallas-Fort Worth Arlington	4,445,000	12.2	16.6	3.63	78.1	0.7	483	18,703
60	USA	Miami-Fort Lauderdale	5,330,000	18.4	12.6	2.91	83.0	3.8	427	15,488
61	USA	Washington	4,280,000	14.3	15.8	4.23	68.8	4.9	475	21,476
62	USA	Houston	3,790,000	11.3	16.4	3.46	81.5	1.3	511	18,692

No	Nation	Urban	Population	Urban density	Average distance Private motorized Modes (km/trip)	Number of daily Trips	Private motorized modes(%)	Public mode(%)	Private car ownership (vehicles/ 1,000inhabitant)	Transport energy Consumption (MJ/person)
63	USA	Detroit	4,055,000	12.4	14.7	4.08	74.7	1.8	483	17,229
64	USA	Boston	4,075,000	7.4	12.7	4.35	73.7	5.0	543	18,437
65	USA	Atlanta	4,170,000	8.2	15.6	4.10	77.4	2.7	509	20,591
66	USA	San Francisco -Oakland	4,140,000	16.6	14.4	3.86	77.4	2.8	597	19,197
67	USA	Phoenix	3,270,000	15.8	14.0	3.93	75.0	2.5	389	17,495
68	USA	Seattle	3,005,000	12.2	14.2	4.82	71.6	3.3	509	22,623
69	USA	Minneapolis-St. Paul	2,520,000	10.9	14.8	4.56	72.2	2.8	555	30,467
70	USA	San Diego	2,905,000	14.4	13.8	3.98	78.9	2.4	566	19,691
71	USA	St. Louis	2,105,000	9.8	16.4	4.06	71.8	1.5	615	20,056
72	USA	Baltimore	2,315,000	13.1	15.8	4.23	68.8	4.9	468	21,476
73	USA	Pittsburgh	1,800,000	8.2	16.4	3.68	61.1	4.8	655	22,706
74	USA	Tampa-St. Petersburg	2,250,000	10.8	13.2	3.88	77.8	0.7	543	20,230
75	USA	Denver Aurora	2,090,000	16.2	14.3	4.36	79.0	1.7	195	22,422
76	USA	Cleveland	1,790,000	10.7	13.8	4.03	70.4	2.9	687	33,645
77	USA	Cincinnati	1,620,000	9.3	15.5	4.36	70.8	1.5	594	20,586
78	USA	Portland	1,730,000	14.1	14.3	3.62	69.3	2.0	558	17,287
79	USA	Kansas City	1,500,000	9.9	13.1	4.29	81.3	1.1	181	21,534
80	USA	Sacramento	1,750,000	18.4	15.2	4.14	73.2	1.8	678	21,761
81	USA	San Antonio	1,360,000	12.9	15.5	3.30	75.3	1.9	502	15,790
82	USA	Orlando	1,360,000	11.6	13.2	3.74	80.6	1.0	573	17,618
83	USA	Columbus	1,195,000	11.7	14.7	4.23	67.1	1.2	161	39,980
84	USA	Providence	1,245,000	9.6	15.3	3.64	79.4	1.9	665	17,510
85	USA	Norfolk-VA Beach-Newport News	1,540,000	11.3	13.2	4.49	76.3	2.4	541	26,343
86	USA	Indianapolis	1,035,000	7.2	14.5	3.80	72.8	2.8	670	19,725
87	USA	Milwaukee	1,460,000	11.6	13.3	3.49	75.2	2.5	445	15,596
88	USA	Charlotte	860,000	7.7	14.6	4.78	73.8	2.1	665	17,816
89	USA	New Orleans	1,090,000	21.3	12.8	3.95	78.2	2.9	508	20,240
90	USA	Nashville Davidson	990,000	8.9	16.2	4.67	72.7	0.2	638	23,291
91	USA	Austin	855,000	10.4	15.1	3.44	76.0	1.4	654	18,045
92	USA	Memphis	1,020,000	9.8	20.5	4.17	60.3	1.0	540	22,357
93	USA	Buffalo-Niagara Falls	1,130,000	11.9	11.8	3.81	73.5	3.0	518	15,331
94	USA	Louisville	905,000	8.9	12.2	3.80	83.1	1.0	567	17,737
95	USA	Hartford	890,000	7.3	15.0	3.45	79.1	1.6	769	2,352
96	USA	Jacksonville	990,000	9.3	15.2	5.18	71.5	1.1	588	26,915
97	USA	Oklahoma City	850,000	10.2	13.3	3.49	69.4	0.8	706	13,237
98	USA	Rochester	1,041,000	13.7	16.4	4.03	61.9	3.1	553	17,288
99	USA	Salt Lake City	970,000	16.3	11.2	3.38	79.7	2.4	468	14,041
100	USA	Honolulu	876,000	22.1	11.5	3.18	83.5	3.1	386	13,552
101	Malaysia	Kuala Lumpur	1,390,800	57.2	8.2	2.80	58.4	7.5	208	9,221
102	Philippines	Manila	9,454,000	148.6	7.5	2.39	32.9	17.3	85	5,298
103	Lebanon	Tripoli	305,732	87.1	13.7	2.13	50.1	14.3	282	2,445
104	Syria	Damascus	3,078,190	12.4	12.2	1.44	24.6	44.4	20	1,548
105	Nicaragua	Managua	1,200,000	3.5	14.5	1.99	36.6	35.0	43	5,276
106	Romania	Bucharest	2,149,000	36.0	17.5	2.79	26.6	47.3	191	6,713
107	China	Chengdu	3,068,312	52.4	11.5	2.56	13.8	5.2	54	1,747
108	Brazil	Sao Paulo	18,300,000	85.8	9.1	1.78	33.6	29.0	238	4,428
109	Vietnam	Ho Chi Minh	5,285,000	30.0	8.1	2.38	71.3	2.6	12	8,252
110	Vietnam	Hanoi	3,183,000	34.6	16.7	2.87	6.3	2.1	11	899
111	Cambodia	Phnom Penh	1,152,000	26.2	7.7	2.16	59.4	3.9	42	817
112	Egypt	Cairo	6,800,992	106.3	13.8	2.84	35.0	32.5	91	7,747
113	Indonesia	Jakarta	5,306,589	45.5	13.1	3.67	21.5	12.4	98	4,971
114	Peru	Lima	8,043,256	28.8	11.4	2.06	34.1	41.8	48	2,348
115	Kenya	Nairobi	4,041,900	58.1	32.3	1.83	24.5	3.8	51	3,536
116	China	Hong Kong	6,720,000	286.0	9.0	2.57	16.2	46.0	51	2,562
117	Singapore	Singapore	3,320,000	102.0	9.7	2.87	45.1	40.9	123	8,139
118	Arab Emirates	Dubai	910,000	33.6	11.0	2.56	77.3	6.7	243	11,005
119	Australia	Melbourne	3,370,000	13.7	10.0	3.72	76.0	6.0	578	17,002

3.5 Relationship between urban density, transportation energy consumption and travel characteristics

Next, Table 3-10, using the definitions in Table 3-8 and the calculation methods in Table 3-9, shows the database. This database was built from the average trip length, average number of daily trips, modal share of private motorizes modes, and car ownership for 119 metropolitan areas in 38 countries.

While Newman and Kenworthy have contributed significantly to the understanding of the relations between urban density and transportation energy consumption, it could be argued that their work does not elucidate the influences of individual travel behaviors on transportation energy consumption and that the space-time context of cities was not resolved in their empirical-analysis work. Additionally, I have investigated the correlations between travel behaviors of Private Motorized modes (PMM) and urban density. Similar to Newman and Kenworthy's (1989a, 1989b) findings, urban density and transportation energy consumption for the private motorized modes are strongly correlated (Figure 3-2).

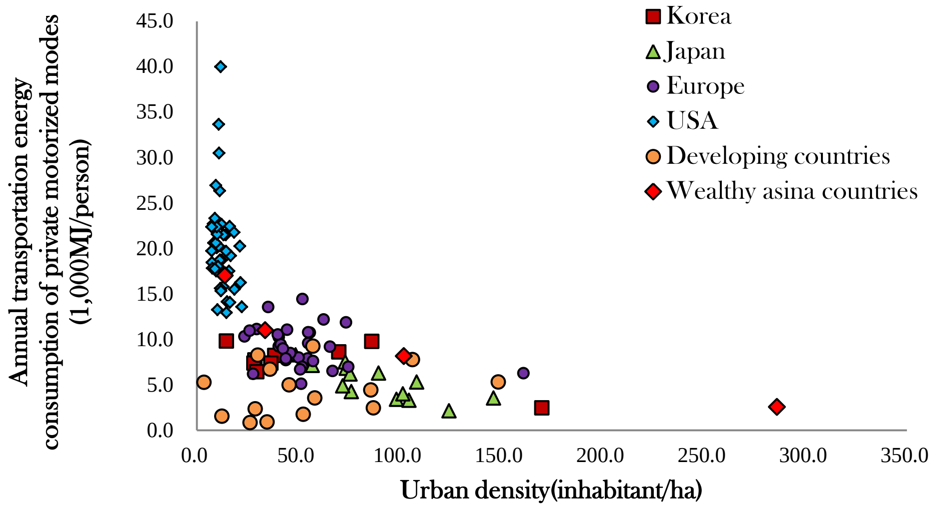

Figure 3-2 Relationship between urban density and urban transportation energy consumption

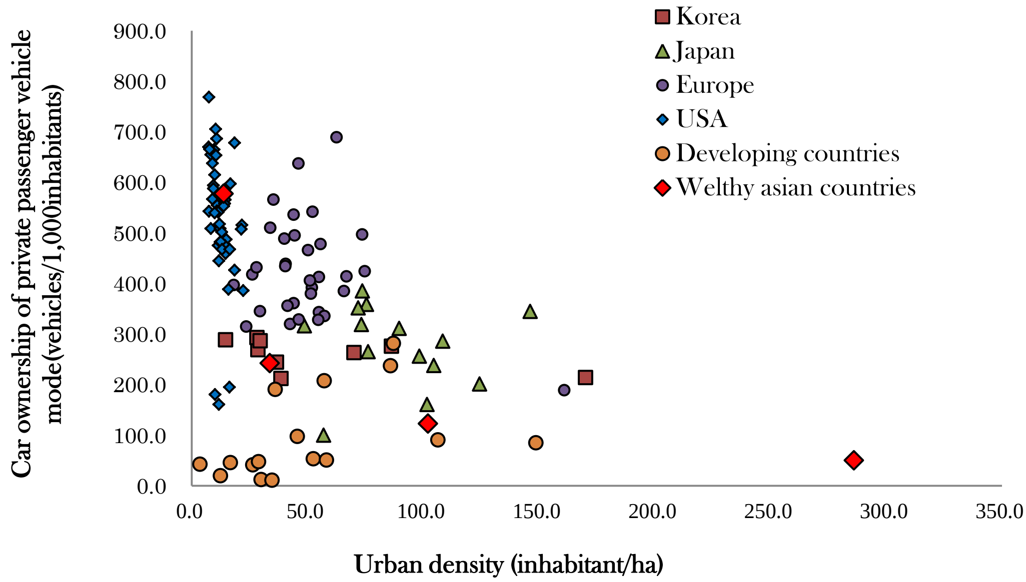

Figure3-3 Relationship between urban density and private car ownership

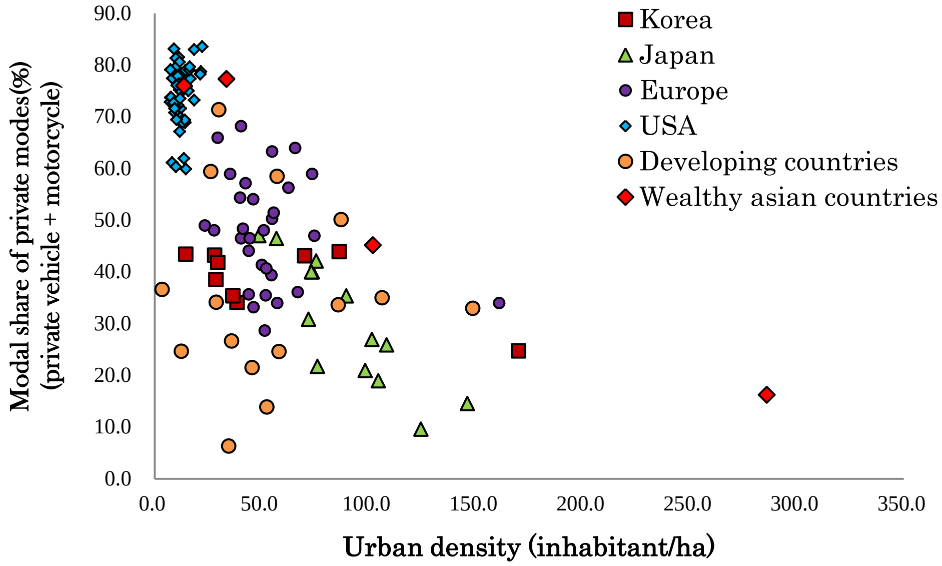

Figure 3-4 Relationship between urban density and modal share of private modes

Although transportation energy consumption and urban density may be strongly correlated on the city level, this correlation does not necessarily reflect a causal mechanism. To determine causality, the micro level of individuals should be considered. Kenworthy et al. (1999) argued that a city is an organic body and not an aggregation composed of personal travel characteristics. In other words, they regard a city as one big unit and assume that people travel with the same tendencies throughout the city and did not consider the influence of purpose on people's travel behaviors.

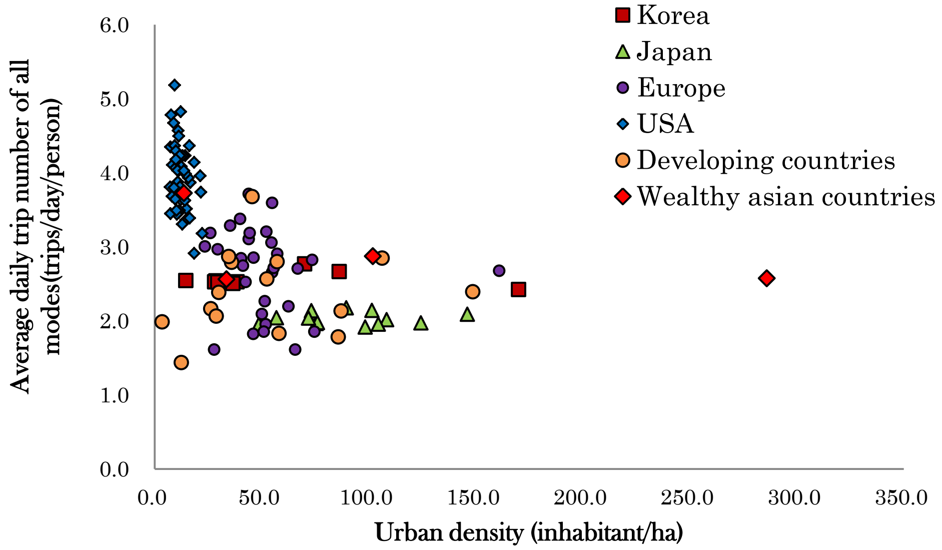

Figure 3-5 Relationship between urban density and number of daily trips

However, from a perspective of individual preference on modal choice, it has been argued that the relation between travel and land use must be considered and that observed correlations between travel and urban structure reflect the self-selection processes on travel (Kitamura et al., 1997). As shown in Figure3-3, a dispersed urban structure makes people more dependent on private motorized modes. Excluding developing countries, the urban density strongly influences possession of private passenger vehicle. Private vehicle ownership decreases as the city becomes denser. Figure3-4 depicts the relation between urban density and percentage of private motorized modes in cities. In developed countries, modal share of private motorized modes of transportation decreases as the city density increases. In contrast, the result of developing countries in Figure3-4 is very irregular. This means that the relations between urban density and car dependency hold for developed countries, but not developing countries. That is, the tendency toward car dependency in developing countries could be influenced by economic level rather than the urban density.

Therefore, I expect that the relation between urban density and car dependency would be become stronger in the future as the global economy grows.

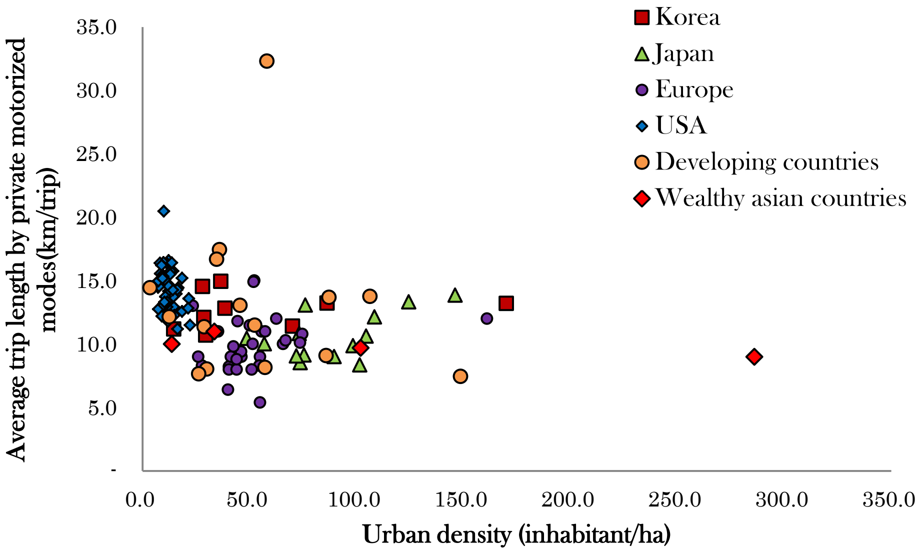

Figure 3-6 Relationship between urban density and trip length

The relationships between private car ownership, characteristics of travel behaviors, and urban density in city as well as those between private car ownership and average modal share of private motorized modes were investigated. The relations between urban density and metropolitan-wide travel patterns differ across the region. Consequently, a dispersed urban structure increases people's tendencies to own and use a private vehicle (Figures 3-3 and 3-4). Generally, US metropolitan areas depend more on private motorized modes more than Asian, European, and developing countries.

Figures 3-5 and 3-6 show how the characteristics of travel behavior differ by region. The average number of daily trips in the USA is nearly one and a half times more than those of the Asian and European countries. It can be assumed that the dispersed urban structure has an effect on the generation of travel behaviors. Urban density and average number of daily trips exhibit a strong negative correlation, indicating the denser the urban structure, the fewer number of daily trips.

Finally, in dispersed urban structures, which are more common in US metropolitan areas, long distance trips are more dominant. The average trip length for private motorized modes (Korea, 12.7 km; Japan, 10.6 km; Europe, 9.9 km; USA, 14.4 km; Developing countries, 13.1 km; Wealthy Asia countries, 9.9 km (Figure 3-6)) could be influenced by the urban density. As the urban population density increases, the average trip length becomes longer. Hence, I conclude that the trip destinations are more spread out in a dispersed urban structure, which increases the average trip length as people conduct local business in a larger area. In contrast, in a denser urban structure, the trip purpose could be completed in a smaller area.

Additionally, public transportation or Non-Motorized Trip (NMT) could be more convenient in a denser urban structure than private motorized modes of transportation. These findings demonstrate that many factors which affect transportation energy consumption (private car ownership, average daily trip number, average modal share of private motorized modes and average travel length on private motorized modes) can have the relationship with urban structure which described with population density in each area.

3.6 Conclusion

This research was conducted to build a database of cities in the world for transportation energy consumption of private motorized vehicles using information of travel behaviors calculated from PT data. The data came from public sources in 119 metropolitan areas in 38 countries. The constructed database provides practical and reliable information, including travel behavior. The data confirms that each country has certain differences in the relationship between individual travel behaviors, the dependence on private automobiles and urban density. Additionally, understanding the relations between urban density and travel behaviors will be invaluable for measures to reduce energy consumption in urban development planning.

Therefore, this database can be used to analyze urban phenomena linked to traffic behavior such as variations in urban mobility.

Notes

(1) KTDB: Korean Transport Database, MLITT: Ministry of Land. Infrastructure, Transport and Tourism, JICA: Japan International Cooperation Agency, UITP: International Association of Public Transportation, FHWA: Federal Highway Administration U.S. Department of Transportation.
(2) Korea: Population and housing census (2005), Wealthy Asian: Periodic surveys(censuses. mobility studies) of International Association of (UITP)2001, countries: The study on master plan for urban transport in the metropolitan area-(Cairo, Tripoli.(2001); Phnom Penh, Chengdu, Jakarta, Kuala Lumpur(2000); Damascus, Managua(1998); Manila(1997); Bucharest(1999); Lima, Hanoi(2005); Ho Chi Minh(2003); Nairobi(2004)).
(3) Korea: Household Travel Survey((2005)-Inchon, Suwon, Sungnam (2006)), Japan: The Nationwide Person Trip Survey(2005), U.S.A: NHTS(National Household Travel Survey, 2001), Developing countries: Household Interview Survey of each country-(Cairo, Tripoli.(2001); Phnom Penh, Chengdu, Jakarta, Kuala Lumpur(2000); Damascus, Managua(1998); Manila(1997); Bucharest(1999); Lima, Hanoi(2005); Ho Chi Minh(2003); Nairobi(2004)).
(4) Korea: The Statistics Report of each city (2005), Japan: The Statistics Report of each city(2005), U.S.A: U.S. Department of Transportation, Federal Highway Administration, Highway Statistics 2001.
(5) U.S.A: Regional Economic Accounts Bureau of Economic Analysis U.S. Department of Commerce http://www.bea.gov/regional/
(6) All of vehicle in this research is assumed as gasoline vehicles (We cannot find out which trip is made by diesel vehicles).
(7) Fuel efficiency of motorcycle is assumed a half of passenger car.

(8) **Table in *Notes*-** The studies on master plan for urban transport in the metropolitan area in developing countries by carrying out Japan International Cooperation Agency (JICA)

*footnote **		
The urban cities having populations of more than 80 thousand that carried out Periodic survays (censuses, mobility studies) of International Association of Public Transport (UITP) in 2001		
*footnote * **		
Toripoli	2000	*The study of Environmental Friendly Integrated Transportation Plan for Greater Tripoli* (JAPAN INTERNATIONAL COOPERATION AGENCY (JICA), COUNCIL FOR DEVELOPMENT AND RECONSTRUCTION (CDR) REPUBLIC OF LEBANON)
Phnom Penh	2000	*The Study on the Transport master plan of the Phnom Penh Metropolitan Area in the Kingdom of Cambodia* (JAPAN INTERNATIONAL COOPERATION AGENCY (JICA), MUNICIPALITY OF PHNOM PENH THE KINGDOM OF CAMBODIA)
Damascus	1998	*The Study on Urban transportation planning of Damascus City in the Syrian Arab Republic* (JAPAN INTERNATIONAL COOPERATION AGENCY (JICA), MUNISTRY OF INTERIOR DAMASCUS GOVERNATE SYRIAN ARAB REPUBLIC)
Manila	1996	*Metro Manila Urban transportation Integration study* (Japan International Cooperation Agency (JICA), Republic of the Philippines)
Chengdu	2000	*Study for Public transportation Improvement in Chengdu city in the peoples Republic of China* (Japan International Cooperation Agency (JICA), THE PEOPLE\`S GOBERNMENRT OF CHENGDU, SICHUAN PROVINCE, PEOPLE\`S PUBLIC OG CHINA)
Managua	1998	*Comprehensive transportation plan in the Municipality of Managua in the Republic of Nicaragua* (Japan International Cooperation Agency (JICA), MUNICIPALITY OF MANAGUA)
Belem	2000	*Update of Master Plan for Urban transport in the Metropolitan Area of Belem (Japan International Cooperation Agency* (JICA), UPDATE OF MASTER PLAN FOR URBAN TRANSPORT IN THE METROPOLITAN AREA OF BELEM)
Bucharest	1998	*The Comprehensive Urban transport study of Bucharest city and its Metropolitan area in the Republic of Romania (Japan International Cooperation Agency* (JICA), MUNICIPALITY OF BUCHAREST REPUBLIC OF ROMANIA)
Cairo	2001	*Transportation Master Plan and Feasibility study of urban transport projects in Greater Cairo region in the Arab Republic of Egypt* (Japan International Cooperation Agency (JICA) and the Higher Committee for Greater Cairo Transport Planning)
Jakarta	2000	*The Study on Integrated Transportation master plan for Jabotabek (Japan International Cooperation Agency* (JICA), National Development Planning Agency (BAPPENAS) Republic of

		Indonesia)
Kuala Lumpur	1999	*A Study on Integrated urban transportation Strategies for Envinmental Improvement in Kuala Lumpur* (Japan International Cooperation Agency (JICA), THE FEDERAL TERRITORY DEVELOPMENT AND KLANG VLLEY PLANNING DICISION PRIME MINISTER`S DEVELOPMENT GOVERNMENT OF MALAYSIA)
Ho Chi Minh	2003	The study on urban transport master plan and Feasibility study in HO CHI MINH Metropolitan Area (JAPAN INTERNATIONAL COOPERATION AGENCY (JICA), MINISTRY OF TRANSPORT, SOCIALIST REPUBLIC OF VIETNAM (MOT), HO CHI MINH CITY PEOPLE'S COMMITTEE (HCMC-PC))
Hanoi	2005	*The Comprehensive Urban Development Programme in Hanoi Capital City of the Socialist Republic of Vietnam* (HAIDEP)(Japan International Cooperation Agency (JICA), Hanoi People's Committee)
Lima	2005	*The Master plan for Lima and Callao Metropolitan Area urban transportation in the Republic of Peru* (JAPAN INTERNATIONAL COOPERATION AGENCY (JICA), MINISTRY OF ROADS AND PUBLIC WORKS INISTRY OF LOCAL GOVERNMENT THE REPUBLIC OF KENYA)
Nairobi	2004	*The study on master plan for Urban Transport in the NAIROBI Metropolitan area in the Republic of KENYA* (JAPAN INTERNATIONAL COOPERATION AGENCY (JICA), TRANSPORT COUNCIL OF LIMA AND CALLAO MINISTRY OF TRANSPORTATIONS AND COMMUNICATIONS OF THE REPUBLIC OF PERU)

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CHAPTER 4

Relationship between urban density, travel characteristics and transportation energy consumption according to economic level

4.1 Overview of this chapter

In recent years, the range of individual travel behavior is expanding with the progress of motorization, and this parallels economic development in cities of the world. Urban structure is also changing to suburbanization as the urban population is moving outside of city. Moreover, this movement is linked to increases in transportation energy consumption, and has caused serious urban problems such as air pollution and excessive energy consumption.

With the increasing number of individual vehicles, road space and traffic control measures cannot keep up; the result is traffic congestion, safety, and parking problems. Although the rapid conversion of land from rural to urban areas is mostly due to financial incentives, it provides more transport infrastructure opportunities, which could indirectly increase the demand for automobiles. In turn, higher demand for automobiles could also result in suburban development, leading to long-term urban sprawl in low-density regions accessible only by individual vehicles, as public transport cannot afford to provide service when densities are low. Providing gasoline for private cars and motorcycles and diesel for trucks also leads to rising air pollution, as well as increasing transportation energy consumption (Schipper and Ng, 2004). The consumption of on-road gasoline and diesel in urban areas of the Unite State is reaching to 77% of total fuel consumption in the US (Parshall et al., 2010). In Europe, the concept of compact cities is used as sustainable urban planning order to foster efficient urban space. In Japan, compact cities have been institutionally specified in basic policy of urban planning (Taniguchi et al., 2008).

Activations of individual mobility by the economic development and the progression of motorization are accelerating suburbanization, which in turn expends low density zones around the urban area irrespective of country (Eom and Schipper, 2010). This cannot possibly to say that the policies for reduction of automobile dependence have been successful.

However, there is limited research regarding the characteristics of travel behaviors from the viewpoint of economic level for understanding the relationship between urban density, travel behaviors, and transportation energy consumption. In addition, quantitative analysis of the impact of traffic characteristics on transportation energy consumption based on economic level is insufficient. Moreover, as time progresses traffic demands from private modes of transportation are increasing parallel to economic development worldwide. We have to establish strategies that can improve the energy consumption and urban-transport problems, from a traffic perspective, in order to mitigate the increase of motorization. Therefore, it is critically important to not only estimate the transportation energy consumption of a city, but also to clarify how the relationship between transportation energy consumption and individual travel behaviors differ based on economic status.

Herein I built a database of world cities, as the first step of study regarding the use of economic level to estimate transportation energy consumption of individual motorized modes, with related indicators of travel behaviors based from person trip data from 119 metropolitan areas in 38 countries. Then, I concluded that the correlation between urban density and transportation energy consumption is different by economic level. Additionally, the more economic development, the clearer the correlation between urban density and travel behaviors becomes.

In addition, I extracted 44 cities with the standard 15% of upper and below in GRDP from 119 cities selected based on previous research (Choi et al., 2011). The 44 cities that were extracted from the 26 countries had a population of over 800,000, and differed in economic status. The distribution of the target cities was as follows: 10 cities in Asia (5 cities in Korea and 5 cities in Japan), 14 cities in Europe, 14 cities in the United States, and 6 cities in developing countries.

Finally, I clarified the causal relationship between urban density, travel characteristics, and transportation energy consumption based on variations in economic levels of cities.

4.2 Feature of this chapter

Newman and Kenworhty (1989), Kenworthy et al. (1999), Kenworthy and Laube (1999) highlighted the strong negative correlation between population density and transportation energy consumption, which contributed to the body of research regarding sustainable urban development. However, in general international comparative research on the relationship between transportation and land use has been limited either to comparisons of aggregate national data or to qualitative discussion (Giuliano and Dargay, 2006). These include Newman and Kenworthy's research that found an inverse relationship between urban density and fuel consumption per capita (Newman and Kenworhty, 1989: Kenworthy et al., 1999). Coevering and Schwanen (2006) criticized the point-of-view of Newman and Kenworthy, and instead suggested that certain unwritten rules were followed with regard to the 'organism of the city', specifically how a city, with regards to transportation and land use, responded to different policy stimuli. This recapitulates the way an organism functions within a certain set of fixed biological rules. Jakapong and Chumnong (2010) analyzed the relationship between urban structure, traffic characteristics, and the relevance of transportation energy consumption in terms of the economic level by looking at motorbike or passenger cars, and their impact on energy consumption or greenhouse gas emissions in Thailand. This research was limited although highlighted the fact that the relationship between urban structure, travel behavior, and transportation energy consumption from the perspective of the economic level of a city was inadequate.

The research explored the differences in 119 cities in South Korea, Japan, Europe, the United States, and developing countries throughout the world based on their level of economic development. In addition, this research exploits Person Trip (PT) data that explains detailed features of travel behaviors in urban areas so that the result retains objectivity and reflects the actual trip conditions. Moreover, the estimation model of transportation energy consumption was developed using a database containing travel behaviors that was aggregated from this PT data. From the data collected above a discriminant analysis was conducted based on the city's urban density and status of economic development. Results showed that traffic characters differed by urban density and geographical location. And with these findings a correlation between urban density, traffic characters and transportation energy consumption was shown to prove the statistical relevance between a city's economic development and the parameters listed above.

4.3 Definition of the trip and estimation method for transportation energy consumption

This research was motivated by such trips generated by Private Motorized Modes (PMM) which are of direct causal relationship with urban transport environment and transport energy consumption. Individual travels increase with urban economic development, and a rapid motorization process is often observed in developing countries in particular with fast economic growth. The data have been extracted from individual travel modes including passenger cars, motorcycles and taxis. The method of extraction is described in CHAPTER 3.4.1.

Transportation energy consumption of the world metropolises are estimated using non-aggregate personal trip data (See for the data specification of each country at the *Notes* towards the end of CHAPTER 3). The basic unit of analysis is individual trip, but the contents of the data differ from country to country. Therefore, standardized estimation criteria of different transport indicators are required and described in CHAPTER 3.4.4.

4.4 Target cities and statistical data related to travel characteristics

119 cities of 32 countries (population above 800,000) have been selected for analysis. This figure is significantly larger than any previous cross comparative analyses research between world cities. To address Newman and Kenworthy's issue of data subjectivity, the cities have been selected on the basis of official publication of transport data, and they are described in CHAPTER 3.3 and Tables 3.4~3.7.

The basic unit of analysis is individual trips of the world urban travelers, but the contents of the data differ from country to country. Therefore, standardized estimation criteria of different transport indicators are required and described in Table 3.8 and 3.9.

4.5 Relationship between travel characteristics, urban density and transportation energy consumption based on economic development

Population density, the most significant measure of urban structure, is a major indicator of the potential represented by travel characteristics in a city. The higher the density is, the greater the proportion of Non-Motorized modes of transport and public transit is generated. This holds true regardless of economic level of a city. It has also been observed, in the result of the researches that the lower the urban density is, the higher transportation energy is consumed(Newman and Kenworthy, 1989). They have also shown that the more intensive land use, the shorter distances of travel, the greater the viability of transit, the greater the amount of walking and biking, the higher the car occupancy of vehicles, the less need for a car so that these patterns suggest that the urban density is fundamental to the creation of travel behavior (Newman and Kenworhty, 1989: Kenworthy et al., 1999: Kenworthy and Laube, 1999).

Using the database, I examined the relationship between travel characteristics, urban density and transportation energy consumption based on the cities economical level. To incorporate the economical development, the cities were categorized into three clusters based on the cities Gross Regional Domestic Product (GRDP). A discriminant analysis was conducted within these clusters to evaluate the relationship between the urban density and travel behavior in a given economic level. Individual characteristics of the travel behaviors were then compared among the different clusters. And finally the transportation energy consumption and its correlation with urban density was evaluated and compared among the three different clusters.

4.5.1 Discriminant analysis on urban density

There has been a considerable amount of research about the relationship between urban population density and characteristics of travel behaviors proving that urban population density plays a key role in characteristics of travel behaviors. However the prior researches were usually limited to a single country with an even economic development lacking the aspect of geographical and economic diversity. In this scent the current research has focused on the relationship of urban density and characteristics of travel behaviors (Passenger car ownership, Road length, Daily trip number of PMM and PUB, Average trip distance of PMM, Speed of PMM and PUB, Modal share of PMM, Car occupancy et al.) through discriminant analysis. The constructed data base was divided into three groups based on its population density. Discriminant analysis was conducted on each group to verify the correlation between the population density and characteristics of travel behaviors through a multi variable statistical method. The theoretical process is explained below.

Multivariable discriminant analysis is conducted by converting numerous individual variables into a one dimensional criterion. Instead of a vector with multiple discriminant variables a one dimensional variable Z, which is composed of numerous variables combined lineally, is used to classify group G_1, G_2 and G_3.

$$Z = B_0 + B_1X_1 + B_2X_2 + \cdots B_pX_p \qquad \textbf{(Eq. 4-1)}$$

B_0 : Discriminant constant

$B_1 \ldots B_p$: Discriminant function coefficient

$X_1 \ldots X_p$: significant variable

In other words discriminant equation Z in (Eq. 4-1) is used to combine discriminant variables to find vector B that best differentiates group G_1, G_2 and G_3. In general, multivariable discriminant analysis has to satisfy the uniformity between covariance matrix and standard deviation. However, it is possible to conduct the analysis by correcting the discriminant equation even if the uniformity is not accomplished.

Table 4-1 Tests of Equality of Group Means

Variables	Wilks' Lambda	F	Sig.
Vehicle (Number of registered passenger car)	.729	21.610	.000
Roadlength (Total road length)	.453	69.926	.000
PMMtrips (Average daily trip number of PMM)	.367	100.027	.000
PUBtrips (Average daily trip number of PUB)	.753	19.073	.000
Dailytrips (Average daily trip number of all modes)	.475	64.188	.000
DistancePMM (Average trip distance of PMM)	.793	15.110	.000
SpeedPMM (Average trip speed of PMM)	.431	76.469	.000
SpeedPUB (Average trip speed of PUB)	.964	2.157	.120
ShareofPMM (Average modal share of PMM)	.542	49.060	.000
Occupancy (Average passenger car occupancy)	.887	7.414	.001

Based on the analysis, the Wilks lambda which evaluates the classification of the average independent variables, shows promising results throughout most of the variables. The PMM trips (Daily trip number of private motorized modes) shows the highest significance with F=100.027, p<0.001 followed by the speed of PMM (F=76.469, p<0.001), rad trip length (F=69.926, p<0.001), share of PMM (F=49.060, p<0.001) indicating a difference in the average values among the cities. However, the average speed of public modes (F=2.157, p.0.05) does not show statistical significance (Table 4-1).

Table 4-2 Summary of Canonical discriminant functions

Function	*1*	*2*
Eigenvalue	2.338	.291
Variance (%)	88.9	11.1
Cumulative (%)	88.9	100.0
Canonical Correlation	.837	.475

Table 4-3 Classification Function Coefficients *(Fisher's linear discriminant functions)*

Variables	Cluster		
	1	*2*	*3*
Vehicle	.025	.024	.023
Roadlength	.002	.002	.003
PMMtrips	-58.883	-61.824	-53.656
PUBtrips	7.371	7.289	9.051
Dailytrips	37.929	40.536	36.555
DistancePMM	1.954	1.960	2.150
SpeedPMM	.209	.284	.321
SpeedPUB	.595	.643	.572
SharePMM	1.659	1.796	1.579
Occupancy	18.612	19.777	20.458
(Constant)	-92.068	-106.342	-105.990

Table 4-4 Classification Results of discriminant analysis

		Cluster	Predicted Group Membership			Total
			1	*2*	*3*	
Original	*Count*	*1*	30	10	0	40
		2	13	21	6	40
		3	2	3	34	39
	%	*1*	75.0	25.0	.0	100.0
		2	32.5	52.5	15.0	100.0
		3	5.1	7.7	87.2	100.0

**: 71.4% (= (30+21+34)/119 x 100) of original grouped cases correctly classified.*

The canonical correlation showed to be 0.837 and 0.475 indicating efficient discrimination. Table 4-3 shows how the variables in a given group influence the grouping process through the Fisher's linear discriminant coefficient. Also figure 4-1 shows the linear discriminant plot.

The final characterization was conducted with Table 4-2 shows the canonical discriminant functions which aids in the relative positioning of the data cases and group centroids. In the current research two canonical discriminant functions are needed for the three different groups. Function 1 has an eigenvalue of 2.338 and 88.9% of the total variance can be explained with the 1st axes while with function 2 11.1% of the total variance can be explained by the 2nd axes. Also the significance levels of both axes are under 0.000 showing validity of the grouping process.

The canonical correlation showed to be 0.837 and 0.475 indicating efficient discrimination. Table 4-4 shows how the variables in a given group influence the grouping process through the Fisher's linear discriminant coefficient. Also figure 4-1 shows the linear discriminant plot. The final characterization was conducted with values from the canonical discriminant function.

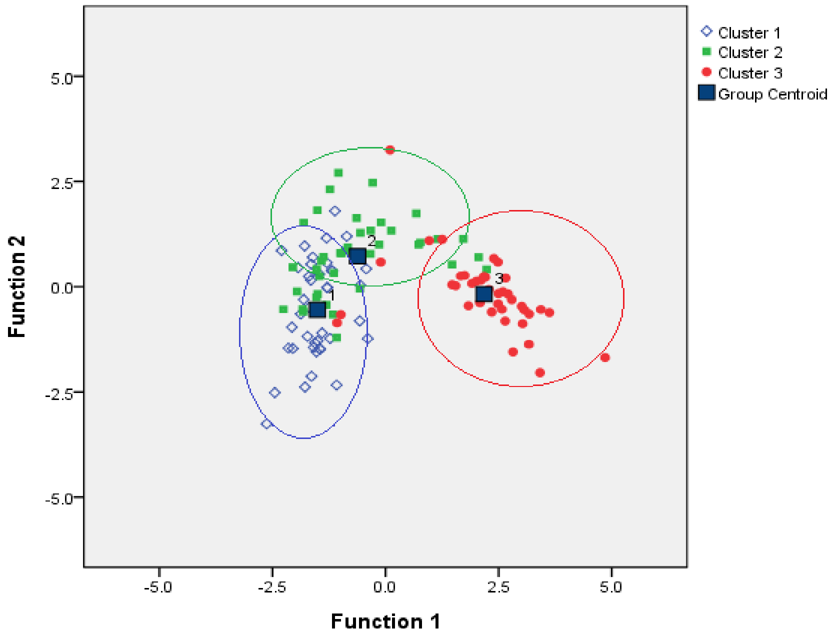

Figure 4-1 Canonical Discriminant Functions

The current research evaluated the characterization based on the first and second discriminant functions which were shown in figure 4-1. Table 4-4 shows the total discriminant results based on the analysis. The total average discrimination was 71.4% while cluster 1 was 75.0%, cluster 2 being 52.5% and cluster 3 87.2%. The results also show a 75.0% and above average accuracy with cities with high and low population densities. This indicates that certain patterns of transportation characters exist in cities with high population densities.

4.5.2 Road length and the number of passenger vehicle

Figure 4-1 and 2a, 2b show the relationship between cities GRDP and its private car ownership as well as the road length. It can be seen that the higher the economic development, the higher the car ownership and road length. This shows that with higher economic development the access of private motorized modes increase alongside the development of the city's infrastructure. However due to the progress of motorization, issues such as urban sprawl is also arising (Nakamura et al., 2004).

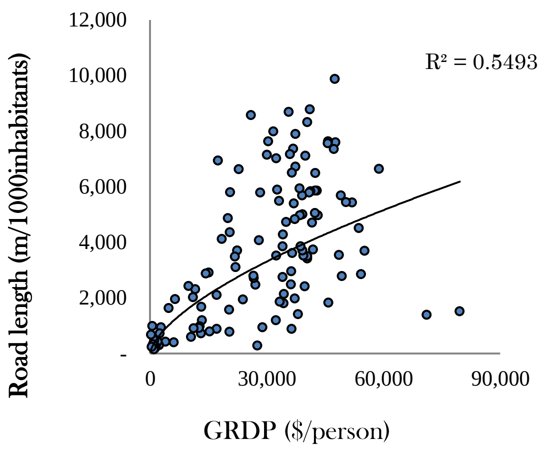

Figure 4-2a GRDP and road length

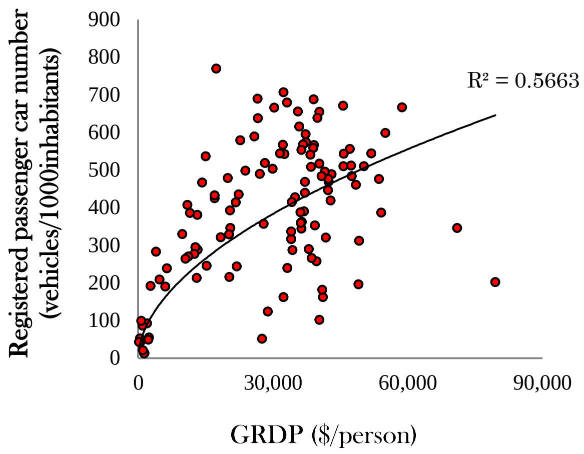

Figure 4-2b GRDP and number of passenger car

Table 4-5 Database of urban density, travel characteristics and transportation energy consumption based on the GRDP of 119 different cities

Country	City	GRDP ($/person)	Car ownership (vehicles/ 1000 people)	Urban density (inhabitants /ha)	Average trip length on private motorized modes (km/trip)	Modal share of private motorized modes (%)	Daily trip number by private motorized modes	Trip speed of private motorized modes (km/h)	Transportation energy consumption (MJ/person)
Top of 40 cities by GRDP									
Japan	Osaka	79,573	202	124.3	13.3	9.6	0.21	25.8	2,148
Japan	Tokyo	71,052	345	146.1	13.9	14.5	0.32	27.7	3,548
USA	Charlotte	58,797	665	7.7	14.6	73.8	4.08	43.5	17,816
USA	San Francisco-Oakland	55,094	597	16.6	14.4	77.4	3.12	44.4	19,197
Japan	Nagoya	54,184	386	73.6	8.6	40.0	0.88	22.5	6,812
USA	Washington	53,667	475	14.3	15.8	68.8	3.32	42.9	21,476
USA	Boston	51,930	543	7.4	12.7	73.7	3.48	42.1	18,437
USA	Seattle	50,319	509	12.2	14.2	71.6	3.93	41.6	22,623
Japan	Fukuoka	49,258	311	89.5	9.0	35.4	0.78	22.7	6,279
USA	Denver Aurora	49,076	195	16.2	14.3	79.0	3.72	43.2	22,422
USA	New York	48,566	460	14.5	12.9	59.9	2.17	39.0	12,931
USA	Dallas-Fort Worth Arlington	47,628	483	12.2	16.6	78.1	3.20	46.9	18,703
USA	Houston	47,487	511	11.3	16.4	81.5	3.06	46.2	18,692
USA	Minneapolis-St. Paul	47,204	555	10.9	14.8	72.2	3.78	46.8	30,467
Germany	Munich	45,800	542	52.2	15.0	40.6	1.30	30.0	14,397
USA	Atlanta	45,748	509	8.2	15.6	77.4	3.52	45.3	20,591
USA	Indianapolis	45,679	670	7.2	14.5	72.8	3.29	44.4	19,725
USA	Chicago,	43,095	488	14.8	12.3	75.8	2.82	38.6	14,113
Norway	Oslo	42,900	418	26.1	9.0	59.1	1.88	36.0	10,908
USA	Salt Lake City	42,484	468	16.3	11.2	79.7	2.79	43.5	14,041
USA	Philadelphia,	42,368	475	11.4	12.9	69.3	3.10	40.3	18,738
USA	Milwaukee	42,352	445	11.6	13.3	75.2	2.95	45.3	15,596
Japan	Hiroshima	41,868	320	73.2	10.9	40.0	0.88	24.5	7,524
Switzerland	Zurich	41,600	495	44.5	11.8	46.4	1.48	32.0	11,013
USA	Columbus	41,218	161	11.7	14.7	67.1	2.17	43.9	39,980
USA	Kansas City	41,024	181	9.9	13.1	81.3	3.79	45.4	21,534
USA	Detroit	40,918	483	12.4	14.7	74.7	3.45	45.8	17,229
USA	Los Angeles-Long Beach-Santa Ana	40,403	516	21.6	13.6	78.7	3.01	42.4	16,217
Japan	Sendai	40,397	101	56.9	10.0	46.4	1.02	25.2	7,116
USA	Austin	40,395	654	10.4	15.1	76.0	3.10	44.8	18,045
USA	Nashville-Davidson	39,946	638	8.9	16.2	72.7	3.98	48.7	23,291
Japan	Kyoto	39,753	256	98.3	9.9	20.9	0.46	22.8	3,397
Japan	Chiba	39,433	352	71.8	9.1	30.8	0.68	24.8	4,892
USA	San Diego	39,181	566	14.4	13.8	78.9	3.21	44.8	19,691
USA	Cleveland	39,151	687	10.7	13.8	70.4	3.36	43.8	33,645
USA	Portland	39,060	558	14.1	14.3	69.3	2.97	42.7	17,287
Japan	Kobe	38,705	265	76.1	13.1	21.7	0.48	27.9	4,238
USA	New Orleans	38,517	508	21.3	12.8	78.2	3.23	40.8	20,240
USA	Memphis	38,419	540	9.8	20.5	60.3	3.42	47.9	22,357
Korea	Ulsan	38,044	289	14.6	11.2	43.4	1.10	25.1	9,785
	Average	**45,807**	**446**	**32.1**	**13.3**	**61.1**	**2.49**	**38.3**	**16,178**
Middle of 40 cities by GRDP									
USA	Orlando	37,394	573	11.6	13.2	80.6	3.20	40.8	17,618
USA	Cincinnati	37,323	594	9.3	15.5	70.8	3.75	43.4	20,586
France	Paris	37,200	439	40.5	8.2	46.4	1.30	22.0	9,187
USA	Baltimore	37,196	468	11.3	15.8	68.8	3.78	42.9	21,476
USA	Phoenix	36,984	389	15.8	14.0	75.0	3.07	46.2	17,495
USA	Louisville	36,762	567	8.9	12.2	83.1	3.36	40.5	17,737
Finland	Helsinki	36,500	361	44.0	8.8	44.0	1.36	33.0	7,851
USA	Rochester	36,431	553	13.7	16.4	61.9	3.35	47.0	17,288
UK	London	36,400	343	54.9	9.0	50.2	1.33	23.0	9,560
Japan	Sapporo	36,289	359	75.4	9.2	42.1	0.93	25.1	6,191
USA	Honolulu	36,181	386	22.1	11.5	83.5	2.74	36.0	13,552
USA	St. Louis	35,919	615	9.8	16.4	71.8	3.43	46.7	20,056
USA	Pittsburgh	35,617	655	8.2	16.4	61.1	2.90	42.8	22,706
USA	Miami-Fort Lauderdale	35,001	427	18.4	12.6	83.0	2.44	36.6	15,488

Country	City	GRDP ($/person)	Car ownership (vehicles/ 1000 people)	Urban density (inhabitants /ha)	Average trip length on private motorized modes (km/trip)	Modal share of private motorized modes (%)	Daily trip number by private motorized modes	Trip speed of private motorized modes (km/h)	Transportation energy consumption (MJ/person)
Japan	Yokohama	34,418	287	108.4	12.1	25.8	0.57	28.0	5,304
Austria	Vienna	34,300	414	66.9	10.3	36.0	0.97	24.0	6,483
Japan	Kitakyushu	34,145	316	48.6	10.5	47.0	1.03	26.6	8,298
Denmark	Copenhagen	34,100	315	23.5	13.0	48.9	1.47	39.0	10,306
Netherlands	Amsterdam	34,100	336	57.3	11.0	33.9	0.98	29.0	7,591
Japan	Kawasaki	33,287	239	104.5	10.6	18.9	0.42	25.0	3,305
USA	Sacramento	33,163	678	18.4	15.2	73.2	3.26	47.3	21,761
USA	Norfolk-VA Beach-	32,662	541	11.3	13.2	76.3	3.78	44.5	26,343
Japan	Saitama	32, 441	161	101.5	8.4	26.9	0.59	22.5	4,001
USA	Oklahoma City	32,439	706	10.2	13.3	69.4	2.93	43.6	13,237
Germany	Stuttgart	32,300	566	35.3	11.0	58.9	1.93	37.0	13,514
USA	Tampa-St. Petersburg	31,663	543	10.8	13.2	77.8	3.39	40.6	20,230
USA	Providence	30,340	665	9.6	15.3	79.4	3.15	45.6	17,510
USA	San Antonio	30,005	502	14.4	15.5	75.3	2.88	42.4	15,790
Singapore	Singapore	28,900	123	102.0	9.7	45.1	1.29	25.3	8,139
USA	Buffalo-Niagara Falls	28,301	518	11.9	11.8	73.5	3.13	39.3	15,331
Netherlands	Rotterdam	28,000	356	41.4	9.3	48.3	1.32	25.0	9,428
China	Hong Kong	27,600	51	286.0	9.0	16.2	0.42	22.5	2,562
France	Lyon	27,100	489	40.0	8.4	54.3	1.83	20.0	10,518
Italy	Turin	26,700	637	46.1	10.4	54.0	0.98	22.0	8,447
Italy	Rome	26,600	689	62.6	12.0	56.2	1.23	23.0	12,156
USA	Jacksonville	25,901	588	9.3	15.2	71.5	4.50	43.8	26,915
Belgium	Brussels	23,900	497	73.6	10.1	58.9	1.66	28.0	11,828
Australia	Melbourne	22,800	578	13.7	10.0	76.0	2.83	—	17,002
UK	Manchester	22,400	434	40.4	8.0	68.1	1.93	32.0	10,222
Arab	Dubai	22,000	243	33.6	11.0	77.3	1.98	44.0	11,005
	Average	**32.019**	**455**	**43.1**	**11.8**	**59.2**	**2.18**	**34.5**	**13,350**
Bottom of 39 cities by GRDP									
France	Lille	21,800	413	55.0	5.4	63.2	2.27	20.0	10,754
UK	Glasgow	20,600	345	29.5	8.0	65.9	1.95	28.0	11,084
Spain	Bilbao	20,500	392	51.9	14.9	35.4	0.69	33.0	6,942
Korea	Seoul	20,371	215	170.1	13.2	24.7	0.60	20.8	2,438
Germany	Berlin	20,300	328	54.7	8.3	39.3	1.20	24.0	7,874
Spain	Madrid	20,000	478	55.7	11.0	51.4	1.39	30.0	10,719
UK	Newcastle	18,400	320	42.5	9.8	57.1	1.44	36.0	8,956
USA	Hartford	17,419	769	7.3	15.0	79.1	3.03	46.9	22,352
Spain	Barcelona	17,100	424	74.7	10.8	46.9	0.87	26.0	6,934
Portugal	Lisbon	17,100	432	27.9	8.3	48.0	0.77	20.0	6,193
Korea	Inchon	15,296	245	36.5	15.0	35.3	0.88	24.5	7,372
Czech Republic	Prague	15,100	536	44.0	8.0	35.6	1.32	25.0	7,706
Spain	Valencia	14,300	466	50.2	11.5	41.3	0.86	24.0	7,965
Korea	Daejeon	13,318	287	29.5	10.7	41.8	1.05	23.1	6,425
Poland	Warsaw	13,200	380	51.5	10.0	28.6	0.65	25.0	5,077
Korea	Pusan	13,086	212	38.5	12.8	34.0	0.86	23.8	8,231
Korea	Kwangju	12,776	294	28.1	14.6	43.2	1.09	33.3	7,359
Korea	Suwon	12,595	276	86.2	13.3	43.9	1.17	28.5	9,781
Greece	Athens	11,600	385	65.7	10.0	63.9	1.03	20.0	9,169
Korea	Daegu	11,201	269	28.6	12.1	38.5	0.98	24.9	7,714
Spain	Seville	11,000	406	51.1	8.0	48.0	0.89	21.0	6,670
Korea	Sung Nam	10,550	263	70.1	11.4	43.1	1.19	23.9	8,613
Hungary	Budapest	9,840	329	46.3	9.0	33.1	0.94	20.0	8,197
Brazil	Sao Paulo	6,420	238	85.8	9.1	33.6	0.60	18.2	4,428
Russia	Moscow	6,060	189	161.0	12.0	33.9	0.91	27.0	6,251
Malaysia	Kuala Lumpur	4,816	208	57.2	8.2	58.4	1.64	14.9	9,221
Lebanon	Tripoli	3,990	282	87.1	13.7	50.1	1.07	37.4	2,445
Romania	Bucharest	2,830	191	36.0	17.5	26.6	0.74	32.6	6,713
China	Chengdu	2,442	54	52.4	11.5	13.8	0.35	40.8	1,747
Peru	Lima	2,299	48	28.8	11.4	34.1	0.70	16.8	2,348
Egypt	Cairo	2,019	91	106.3	13.8	35.0	0.99	19.0	7,747
Vietnam	Ho Chi Minh	1,460	12	30.0	8.1	71.3	1.70	23.8	8,252
Vietnam	Hanoi	1,350	11	34.6	16.7	6.3	0.18	26.0	899
Syria	Damascus	1,088	20	12.4	12.2	24.6	0.35	33.3	1,548
Philippines	Manila	1,030	85	148.6	7.5	32.9	0.79	10.0	5,298
Indonesia	Jakarta	710	98	56.6	13.1	21.5	0.79	19.3	4,971

Country	City	GRDP ($/person)	Car ownership (vehicles/ 1000 people)	Urban density (inhabitants /ha)	Average trip length on private motorized modes (km/trip)	Modal share of private motorized modes (%)	Daily trip number by private motorized modes	Trip speed of private motorized modes (km/h)	Transportation energy consumption (MJ/person)
Nicaragua	Managua	620	43	3.5	14.5	36.6	0.73	26.0	5,276
Kenya	Nairobi	421	51	58.1	32.3	24.5	0.45	34.1	3,857
Cambodia	Phnom Penh	215	42	26.2	7.7	59.4	1.28	29.3	817
	Average	**10,134**	**264**	**55.9**	**11.8**	**41.1**	**1.04**	**25.9**	**6,829**

People's travel range has expanded due to motorization parallel to economic development, and urban structure is changing with suburbanization. Thus raises the need to understand the relationship between urban density and transportation characteristics.

4.5.3 Urban density and characteristics of travel behaviors based on economic level

To assess the relationship between urban density and characteristics of travel behaviors based on economic development, a database of 119 cities around the world were divided into three groups based on its GRDP. By separating the cities by their economic development it was possible to compare the transportation characteristics, urban density and energy consumption based on the different development level and the relationships among the groups as well.

Table 4-5 reveals the population density of each city with the lowest in the United States (average density: 11.5 inhabitants/ha), medium in Europe (average density: 57.1 inhabitants/ha), and highest in Asia (average density: 75.8 inhabitants/ha).

Table 4-5 shows the average values of different transportation characteristic parameters based on the three GRDP groups above. The maximum values are shown in bold and as seen in the discriminant analysis the values were largest at cities with the highest or lowest densities.

Table 4-6 Urban density and travel characteristics by GRDP

valuables	unit	Top by GRDP	Middle by GRDP	Bottom by GRDP
Urban density	inhabitants/ha	32.1	43.1	55.9
Num. of private car	1000vehicles/inhabitants	446	455	264
Road length	m/1000 inhabitants	5,122	4,394	1,759
Daily trip number	trips/person/day	3.46	3.19	2.48
Daily trip number by PMM	trips/person/day	2.49	2.18	1.04
Average trip distance by PMM	km/trip	13.3	11.8	11.8
Average speed of PMM	km/hour	38.3	34.5	25.9
Average speed of PUB	km/hour	22.8	26.6	25.3
Modal share of PMM	%	61.1	59.2	41.1
Passenger car occupancy	Persons/vehicle	1.60	1.51	1.65
Transportation energy consumption	MJ/year	16,178	13,350	6,829

(1) Daily trip number including PMM

Giuliano and Dhiraj (2003) determined that more trips occur within lower density areas of cities in US and Britain. Their result has been highlighted in existing studies regarding the fact that the daily trip number can be influenced by urban density. This finding was also reinforced in the current study where the cities with low urban density in the United States daily trip numbers by PMM were found to be an average 3.25 trips/day. It is extremely high, and more than two times that of cities in Europe (1.28 trips/day) and in Japan as well as Korea (0.79 trips/day).

From this, it can be conjectured that trips by private motorized modes increases with the city’s economic level and decreases with the urban density, where higher economic levels lead to more ownership of individual transportation fleets. However, with the cities in lower economic states generally show a different trend where more daily trips are generated in denser urban populations.

(2) Average trip distance of PMM

Next is the relationship between population density and trip length by PMM. Table 4-6 shows that shorter trip lengths are generated in denser urban density. Average trip length by PMM in US cities is 14.4 km/trip. It is longer than European cities (9.9 km/trip) and cities in Japan and Korea (11.7 km/trip). This may explain why the maximum distance between an individual's residence and workplace location can be shorter in dense cities as Coevering and Schwanen (2006) demonstrated. They said that urban structure, determined by population density and job density, is the only variable to be statistically significantly related to commuting distance. A higher percentage of jobs in the inner city lead to a shorter average commuting distance and higher passenger car share. With cities in the bottom GRDP group this rule was also applicable in general. However depending on the economic level within this group, a few of the cities showed irregular relationship between the trip distance and population density. This may be due to the fact that the integration of the industrialized areas and residential areas were integrated differently from other more developed cities.

(3) Average trip speed of PMM and PUB

The relationship between average trip speed by PMM and urban density shows higher speeds in cities with a higher economic level. In particular, the propensity for trip speed to become faster in lower density areas was also very clear. This pattern of low density and faster trip speed was confirmed by the overall pattern in the data.

The city with the fastest trip speed was Nashville (48.7 km/hour) in the USA, where population density is intensely low and is in the top GRDP group. On the other hand, the city with the slowest trip speed was Manila (10.0km/hour) where population density is quite high and is grouped in the higher economic level in the bottom GRDP ranking..

(4) Modal share and urban density

Table 4-7 Modal share by economic level

	Private motorized modes (%)	Public Modes (%)	Non-motorized Modes (%) (Walking, Bicycling)
Top by GRDP	61.1	6.9	18.7
Middle by GRDP	59.2	12.0	22.0
Bottom by GRDP	41.1	22.7	31.3
Average	53.8	13.9	24.0

Among the three different economic groups (GRDP) it can be seen in Table 4-7 that with a lower economic development level there is a higher reliance on public modes. Considering the fact that the urban density is lower with the more economically developed groups (Table 4-6), it can be conjectured that higher urban population density leads to a higher utilization of private motorized modes.

This trend is prominent in cities among the top GRDP group where the less dense cities in the United States and Europe show a high PMM share compared to its counter parts in Japan (where the population density is high). This negative trend can also be seen within the United States where cities with higher population density (such as New York, Washington, Seattle, and Boston) show more frequent use of public transportation and non-motorized modes. That is to say, in cities where the economic level is higher, development of public transportation infrastructure develops alongside with the population density, distributing the modal share throughout private and public methods.

Cities ranked in the mid-GRDP group showed the same negative trends of urban population density and private modal share. However the degree of PMM utilization differs by continent. A higher share of private motorized modes (81.3%) was prominent in cities of the USA compared to Japanese and European cities with similar levels of economic development where the average density of U.S. cities are 12.5 inhabitants/ha and 87.7 inhabitants/ha for Japanese cities. As for Asian and European cities, Asia in general has a denser urban population (average density; Asia: 97.1 inhabitants/ha, Europe: 48.2 inhabitants/ha) followed by a lower PMM considering the population density difference (Modal share of PMM; Asia: 37.4%, Europe: 51.3%). It could be conjectured that this is the result of the development of public transport as well as maintenance of pedestrian spaces as well as non-motorized modes (i.e. walking and bicycling), since both the economic level and population density are high. Therefore, traffic demands on the roads could shift the majority of public transport to non-motorized modes.

Finally, in cities of the bottom GRDP ranking which include mainly developing countries, the modal share of private motorized modes is higher in cities with a high economic level (Tripoli and Kuala Lumpur) compared to cities with a relatively low economic level (Managua, Nairobi, and Phnom Penh).

This factor has shown to have a stronger correlation with the amount of private modal utilization compared to the urban density. From this we can estimate that in developing countries it may be the economic development that determines the amount of private modal utilization rather than the urban density.

As for the countries with rapid economic growth between 1991 and 95, they showed similar motorization development of that of the 1960s in Japan and the United States in its 1960s (Nakamura et al., 2004). Therefore, it can be anticipated that the use of private motorized modes will increase gradually along with the economic development of these developing countries.

(5) Transportation energy consumption

Figure 4-3 shows the relationship between urban density and annual transportation energy consumption per capita. Similar to findings by Newman and Kenworthy and Kenworhty (1989) I can ascertain that in denser cities lesser transportation energy is consumed and the correlation between urban density and transportation energy consumption becomes stronger as the economic level increases.

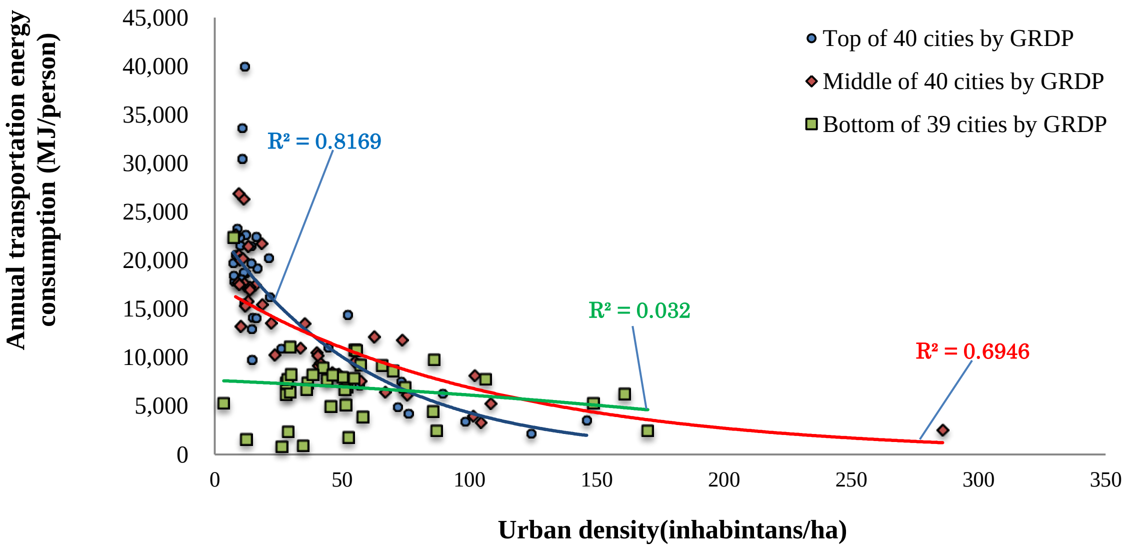

Figure 4-3 Urban density and urban transportation energy consumption according to economic level

I can highlight the fact that transportation energy consumption is much larger in the top GRDP group compared to other target cities. In terms of the top GRDP group, there is no significant difference in energy consumption in the United States showing in general high energy consumption per capita. In the case of European cities, transportation energy consumption of Munich, Zurich, Oslo (12,106 MJ/person), are also higher than other cities in Europe in middle and bottom GRDP ranks (9,609 MJ/person in Middle; 7,874 MJ/person in Bottom). However, transportation energy consumption of New York is visually lower than other cities in the United States; the average daily trip number (2.17 trips/day) and the average trip length (12.9 km/trip) is shorter in New York compared to other cities in the United States. In addition, modal share of public transport (8.1%) is the highest among the cities in the United States. New York is likely a very special case that has a high economic status, a high level of public transport, and relatively higher density compared to other cities in the United States. Overall, in cities in the United States with an extremely low population density and high ownership of passenger car, transportation energy consumption is extremely high regardless of the economic level.

In Asia, the comparison of Japan and Korea represents a model case of the findings of Newman and Kenworthy (1989). Japanese cities are in general having a denser population consumes less energy per capita where Korea consumes almost one and a half more times energy than of Japanese cities.

Lower population density and higher private modal share, along with longer trip length in Korean cities appear to result in higher transportation energy consumption than in Japanese cities.

Table 4-8 Correlation between urban density and travel characteristics, transportation energy consumption

	GRDP	Vehicle	Road length	PMM trips	PUB trips	Daily trips	Distance PMM	Speed PMM	Speed PUB	Share PMM	Occupancy	Energy consumption
	Top by GRDP											
Density	.485**	-.522**	-.681**	-.867**	.549**	-.830**	-.456**	-.828**	-.916**	.161	-.772**	-.904**
	Middle by GRDP											
	-.187	-.698**	-.665**	-.706**	.806**	-.566**	-.516**	-.626**	.169	-.776**	-.357*	-.834**
	Bottom by GRDP											
	.002	-.098	-.244	-.196	.247	-.008	-.036	-.326*	-.130	-.205	.037	-.179

*: p > 0.05, **: p > 0.01

In cities of the bottom GRDP group, as the economic level of city increases, transportation energy consumption becomes larger regardless of the urban density. In addition, distinct differences in passenger car ownership according to the economic level could be the main cause of the higher transportation energy consumption. Based on this finding, I can say that the economic level of the city influences modal choice or status of infrastructure development and inevitably impacts the management of the traffic demand.

In this sense, Table 4-8 shows the correlation between urban density and car ownership, road length, travel characteristics, and transportation energy consumption by economic level. The important thing here is that there are big differences in correlation between urban density and all travel characteristics by economic level. In cities of top and middle rank by GRDP, all travel characteristics are strongly correlated with urban density. On the other hand, in cities of the bottom rank by GRDP, the correlations between urban density and all travel characteristics contrast with those of top and middle.

All correlation between urban density and travel characteristics in the top and middle GRDP groups are highly significant. All characteristics of travel behaviors (Car ownership, Road length, Trip number, Trip length, Trip speed, Modal share by PMM) have a correlation negative with denser urban structure. However in cities in a lower economic status, the correlations between urban density and travel characteristics are not strong. Therefore, it is still difficult to say that propensities of correlation between urban density and travel characteristics are obvious. From the above findings, I can conjecture that the economic level of a city influences the correlation between urban density, personal mobility and transportation infrastructure as explained by passenger car ownership and road length.

In this way, it can also be suggested that the urban density within a city is fundamental to its travel behaviors and could be the key factor in transportation energy consumption. I would suggest that urban density, directly under the control of physical planners, is central to explaining the patterns in travel behaviors and automobile dependence. In addition, I confirm that car ownership and the development of a city's infrastructure are principal agents of travel behavior. As the economical state of a city changes, the density (Job and residential density) will also change accordingly, influencing the traffic demands and behaviors related to PMM utilization. In other words it could be that the process of motorization and energy consumption occurs according to the specific characteristics of a city's structure and development.

4.6 Result of discriminant analysis

The purpose of this analysis is to demonstrate the relationship between a city's urban density and travel characteristics. For this I divided the cities by the level of population density and proved the strong relationship between urban density and traffic characteristics through discriminant analysis. And also, I divided the cities by their GRDP for clarifying that the correlation between urban density and the travel characteristics by PMM is becoming stronger as economic level increases. This result makes us conjecture that urban sprawl could go along with economic development making automobile dependency stronger.

4.7 Relationship between urban density, travel characteristics and transportation energy consumption according to top/bottom 15% by GRDP

4.7.1 Extracted target cities by top/bottom 15% by GRDP

Here, I extracted 44 cities with the standard 15% of upper and below in GRDP from 119 cities selected based on previous Part. The 44 cities that were extracted from the 26 countries had a population of over 800,000, and differed in economic status (Table 4-9, 4-10). The distribution of the target cities was as follows: 10 cities in Asia (5 cities in Korea and 5 cities in Japan), 14 cities in Europe, 14 cities in the United States, and 6 cities in developing countries.

Table 4-9 Extracted target cities in top/bottom 15% by GRDP

	Extracted cities in Top 15% by GRDP
Asia	Osaka, Tokyo, Nagoya, Fukuoka, Hiroshima
Europe	Munich, Oslo, Zurich, Paris, Helsinki, London, Vienna
USA	Charlotte, San Francisco-Oakland, Washington, Boston, Seattle, Denver Aurora, New York
Developing countries	Sao Paulo, Kuala Lumpur, Tripoli
	Extracted cities in Bottom 15% by GRDP
Asia	Pusan, Kwangju, Suwon, Daegu, Sungnam
Europe	Prague, Valencia, Warsaw, Athens, Seville, Budapest, Moscow
USA	Oklahoma, Tampa-St. Petersburg, Province, San Antonio, Buffalo Niagara Falls, Jacksonville, Hartford
Developing countries	Managua, Nairobi, Phnom Penh

Table 4-10 Database for analysis on the relationship between urban density and travel characteristics, transportation energy consumption

Country	City	GRDP ($/person)	Urban density (person/ha)	Average trip length on PMM (km/trip)	Modal share of PMM (%)	The number of daily trip (Trips/day)	Trip speed of PMM (km/h)	Transportation energy consumption (MJ/person)
Asian cities in Top 15% by GRDP								
Japan	Osaka	79,573	124.3	13.3	9.6	1.97	25.8	2,148
Japan	Tokyo	71,052	146.1	13.9	14.5	2.09	27.7	3,548
Japan	Nagoya	54,184	73.6	8.6	40.0	2.11	22.5	6,812
Japan	Fukuoka	49,258	89.5	9.0	35.4	2.18	22.7	6,279
Japan	Hiroshima	41,868	73.2	10.9	40.0	2.14	24.5	7,524
Average		59,187	101.4	11.1	27.9	2.10	24.6	5,262
Asian cities in Bottom 15% by GRDP								
Korea	Pusan	13,086	38.5	12.8	34.0	2.53	25.8	8,231
Korea	Kwangju	12,776	28.1	14.6	43.2	2.53	27.7	7,359
Korea	Suwon	12,595	86.2	13.3	43.9	2.66	22.5	9,781
Korea	Daegu	11,201	28.6	12.1	38.5	2.54	22.7	7,714
Korea	Sungnam	10,550	70.1	11.4	43.1	2.77	24.5	8,613
Average		12,042	50.3	12.8	40.5	2.60	26.9	8,339
European cities in Top 15% by GRDP								
Germany	Munich	45,800	52.2	15.0	40.6	2.30	30.0	14,397
Norway	Oslo	42,900	26.1	9.0	59.1	2.51	36.0	10,908
Switzerland	Zurich	41,600	44.5	11.8	46.4	2.37	32.0	11,013
France	Paris	37,200	40.5	8.2	46.4	1.84	33.0	9,187
Finland	Helsinki	36,500	52.2	8.8	44.0	2.41	23.0	7,851
UK	London	36,400	26.1	9.0	50.2	1.86	24.0	9,560
Austria	Vienna	34,300	66.9	10.3	36.0	1.97	22.0	6,483
Average		39,886	39.4	10.3	47.7	2.18	28.6	1,1245
European cities in Bottom 15% by GRDP								
Czech Republic	Prague	15,100	44.2	8.0	35.6	2.96	25.0	7,706
Spain	Valencia	14,300	50.2	11.5	41.3	1.13	24.0	7,965
Poland	Warsaw	13,200	51.5	10.0	28.6	1.82	25.0	5,077
Greece	Athens	11,600	65.7	10.0	63.9	1.49	20.0	9,169
Spain	Seville	11,000	51.1	8.0	48.0	1.09	21.0	6,670
Hungary	Budapest	9,840	46.3	9.0	33.1	2.22	20.0	8,197
Russia	Moscow	6,060	161.0	12.0	31.5	2.07	27.0	6,251
Average		11,586	67.1	9.8	40.3	1.83	23.1	7,291
The U.S cities in Top 15% by GRDP								
USA	Charlotte	58,797	7.7	14.6	73.8	4.78	43.5	17,816
USA	San Francisco-Oakland	55,094	16.6	14.4	77.4	3.86	44.4	19,197
USA	Washington	53,667	14.3	15.8	68.8	4.23	42.9	21,476
USA	Boston	51,930	7.4	12.7	73.7	4.35	42.1	18,437
USA	Seattle	50,319	12.2	14.2	71.6	4.82	41.6	22,623
USA	Denver Aurora	49,076	16.2	14.3	79.0	4.36	43.2	22,422
USA	New York	48,566	14.5	12.9	59.9	3.36	39.0	12,931
Average		52,493	12.7	14.6	70.2	4.25	42.4	19,272
The U.S cities in Bottom 15% by GRDP								
USA	Oklahoma City	32,439	10.2	13.3	69.4	3.49	43.6	13,237
USA	Tampa-St. Petersburg	31,663	10.8	13.2	77.8	3.88	40.6	20,230
USA	Providence	30,340	9.6	15.3	79.4	3.64	45.6	17,510
USA	San Antonio	30,005	12.9	15.5	75.3	3.30	42.4	15,790
USA	Buffalo-Niagara Falls	28,301	11.9	11.8	73.5	3.81	39.3	15,331
USA	Jacksonville	25,901	9.3	15.2	71.5	5.18	43.8	26,915
USA	Hartford	17,419	7.3	15.0	79.1	3.45	46.9	22,352
Average		28,010	10.3	14.2	75.2	3.82	43.2	18,766
Cities in developing countries in Top 15% by GRDP								
Brazil	Sao Paulo	6,420	85.8	9.1	33.6	1.78	18.2	4,428
Malaysia	Kuala Lumpur	4,816	57.2	8.2	58.4	2.80	14.9	9,221
Lebanon	Tripoli	3,990	87.1	13.7	50.1	2.13	37.4	2,445
Average		5,075	76.7	10.3	47.4	2.24	23.5	5,365
Cities in developing countries in Bottom 15% by GRDP								
Nicaragua	Managua	620	3.5	14.5	36.6	1.99	18.2	5,276
Kenya	Nairobi	421	58.1	32.3	24.5	1.83	14.9	3,536
Cambodia	Phnom Penh	215	26.2	7.7	59.4	2.16	37.4	817
Average		419	29.3	18.1	40.2	1.99	29.8	3,210

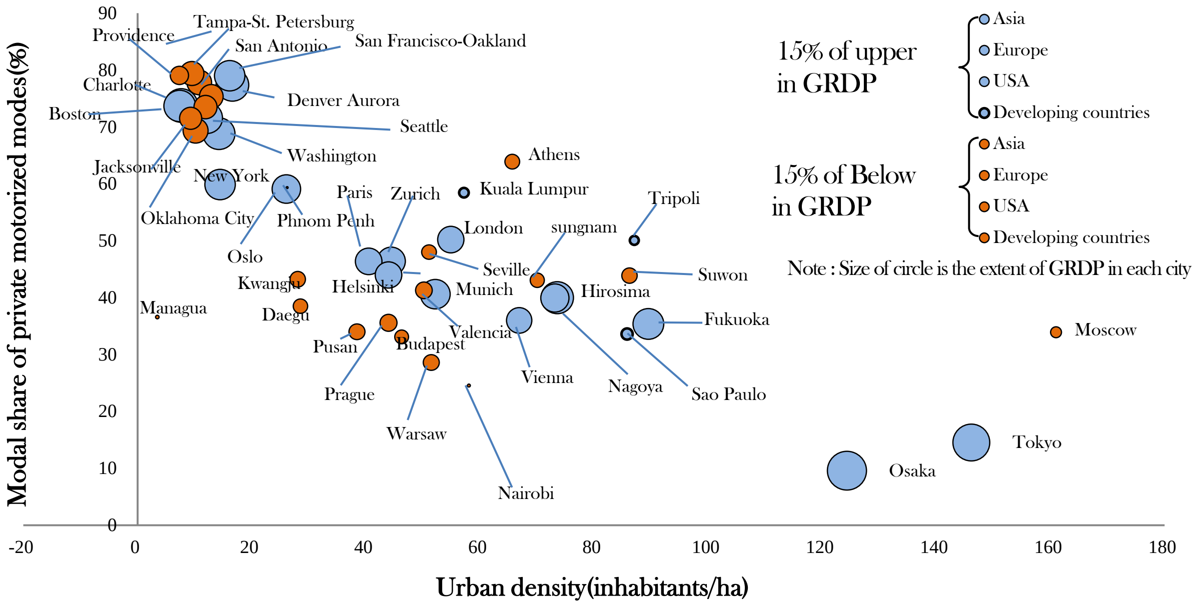

Figure 4-4 Relationship between urban density and modal share of private motorized modes according to economic level

4.7.2 Relationship between urban density and modal share of private motorized modes according to top/bottom 15% by GRDP

First, the relevance of the relationship between urban density and the modal share of private motorized modes in 44 cities in the world are shown in Figure 4-4. It turns out that the population density of each city is lowest in the United States (average density: 11.5 inhabitants/ha), medium in Europe (average density: 57.1 inhabitants/ha), and highest in Asia (average density: 75.8 inhabitants/ha). In cities with lower population density the private modal share was increased. Especially, the cities where population density is very low and where the modal share of private motorized modes is very high are mainly situated in the United States, and it is found that the cities where densely-populated and the modal share of private motorized modes is medium level are mainly Asian cities in Japan or South Korea.

Table 4-11 Registered passenger car in the world according to economic level

	Top 15% by GRDP		Bottom 15% by GRDP	
countries	Urban density (inhabitants/ha)	Passenger car (vehicles/ 1,000inhabitants)	Urban density (inhabitants/ha)	Passenger car (vehicles/ 1,000inhabitants)
Asia	101.4	313	50.3	263
Europe	46.2	430	67.1	384
USA	12.7	492	10.3	613
Developing countries	76.7	243	29.3	45
Average	59.3	370	39.3	383

Next, the analysis of the relationship between economic level and modal share of private motorized modes in cities with comparable population density was conducted. A higher modal share of private motorized modes was revealed in cities with a high economic level, such as London, Paris, Zurich, and Helsinki (average density of 46.0 inhabitants/ha) compared to cities with a relatively low

Table 4-12 Modal share in the world according to economic level

countries	Top 15% by GRDP			Bottom 15% by GRDP		
	Private modes	Public Modes	Non-motorized modes	Private modes	Public modes	Non-Motorized modes
Asia	27.9	15.2	39.4	40.5	25.0	23.6
Europe	46.1	22.6	31.3	40.6	34.1	26.4
USA	72.0	4.0	12.2	75.2	1.6	7.3
Developing countries	47.4	16.9	32.7	40.2	14.2	32.5
Average	48.4	14.7	28.9	49.1	18.7	22.5

economic level, such as Valencia, Warsaw, Budapest, and Prague (average density of 48.0 inhabitants/ha). In this context, Table 4-11 shows that the number of registered passenger cars is higher in citied with high economic levels.

In the case of Asia, modal share of private motorized modes for Tokyo, Osaka, and Nagoya, which are high economic level (average density: 101.4 inhabitants/ha) is lower than Pusan, Kwangju, and Suwon, which are cities with a relatively low economic level (average density: 50.4 inhabitants/ha). It could be conjectured that this is the result of the development of public transport as well as the maintenance of spaces for pedestrian and non-motorized modes (NMM: walking and bicycles), since both the economic level and population density are high; therefore, traffic demands on the roads could shift the majority of public transport to non-motorized modes. According to Table 4-12, the modal share of public transport and non-motorized modes is high.

On the other hand, although there is a difference in the modal share of all modes between in all cities, a similar finding is seldom seen in cities of the United States. In the United States modal share of private motorized modes is lower as the economic level of a city becomes relatively high. In New York, Washington, Seattle, and Boston, which have high economic levels, the use of non-motorized modes (12.1%) and public transport (5.1%) is high. That is to say, in cities where the economic level is higher there is development of public transport and maintenance of space for a pedestrian and non-motorized modes; this holds true for cities in United States that have a low population density.

Lastly, in cities of developing countries, the modal share of private motorized modes is higher in cities with a high economic level (Tripoli and Kuala Lumpur) compared to cities with a relatively low economic level (Managua, Nairobi, and Phnom Penh). Therefore, it is important to mention that the use of private motorized modes increases gradually due to the progress of motorization in the cities in high economic levels of developing countries.

4.7.3 Relationship between urban density and daily trip number excluding Non-Motorized Modes by economic level

Figure 4-5 shows that the relationship between urban density and daily trip number (excluding NMM) is related to differences in economic levels between cities. As population density increases, daily trip number decreases. I found that daily trip number in the United States (3.97 trips/day) was extremely high, and nearly two times that of European cities (2.18 trips/day) and Asian cities (2.3 trips/day). It seems that modal share of private motorized modes becomes highly inevitable since ownership of the individual transportation fleets allows people to move freely, which is needed in the cities of USA where population density is low. Trips for the private purpose are high in the cities of the United States, and this could be due to the fact that urban structure associated with lower population density leads to higher trip frequency. Figure 4-5 appears to indicate that the higher economic level cities have the higher number of daily trip as well.

In the case of European cities, as shown in Table 4-13, the number of daily trips excluding Non-motorized modes in cities with a high economic level (Munich, Oslo, Zurich, Hamburg, and Helsinki) is high and relative to the economic level of cities. Even though the population density of European cities with the same level (54.7 inhabitants/ha in average), the daily trip number increases

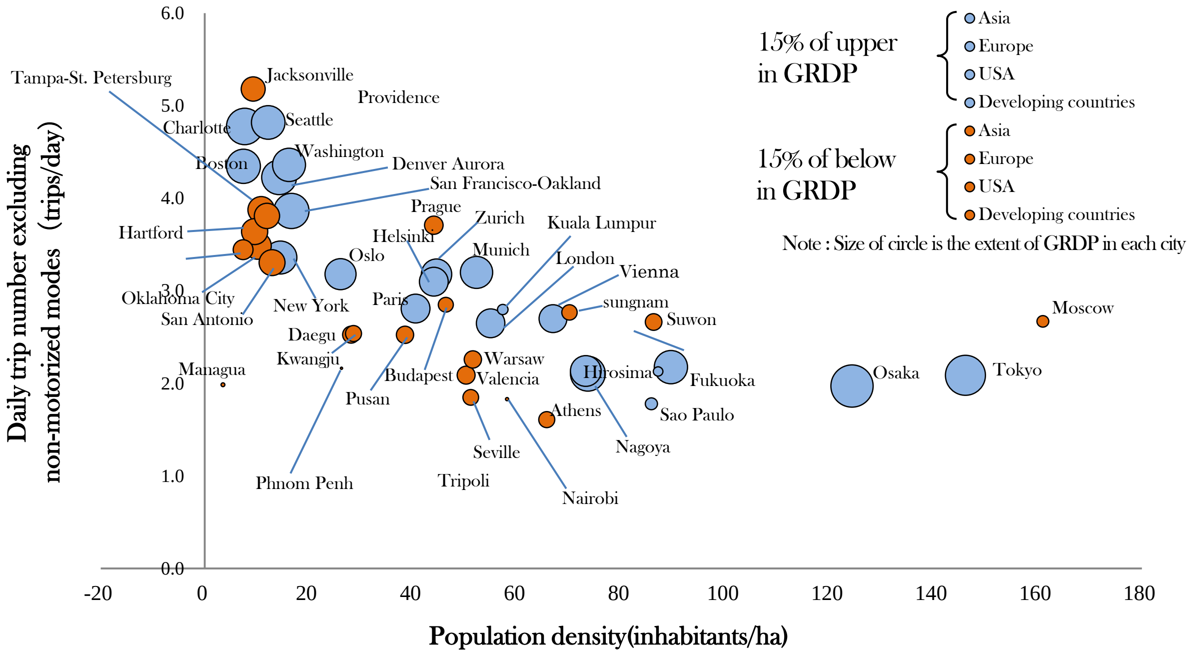

Figure 4-5 Relationship between urban density and daily trip number excluding non-motorized modes

relative to economic level.

In the cities of Japan and Korea, a significant relationship between economic level and daily trip number is not seen. Daily trip number in Korean cities and Japanese cities is almost same. However, the important point here is the difference of modal share of NMM and population density in the two countries. Density of Japanese cities are approximately two times of Korean, but modal share of NMM is much higher than Korean cities, likely due to population density city and high economic level, which undoubtedly have contributed to improvements in infrastructure for pedestrians and bicycle riders. Moreover, shorter trips in inner area could be leaded by NMM.

In the case of developing countries, differences in daily trip number are related to economic level regardless of population density (Table 4-11, 4-12, and 4-13). The number of passenger cars in cities with higher economic levels is higher and trips of working and private purpose are increased. Thus, in developing countries it is likely that the dependence on private motorized modes becomes higher and more trips for private purpose are generated in cities with higher economic levels.

Table 4-13 Density and daily trip number

Countries	Top 15% by GRDP		Bottom 15% by GRDP	
	Urban density (person/ha)	Daily trip number (Trips/day)	Urban density (person/ha)	Daily trip number (Trips/day)
Asia	101.4	2.10	50.3	2.60
Europe	46.2	2.97	67.1	2.43
USA	12.7	4.25	10.3	3.82
Developing countries	76.7	2.24	72.4	1.99
Average	59.3	2.89	50.0	2.71

4.7.4 Relationship between urban density and transportation energy consumption by economic level

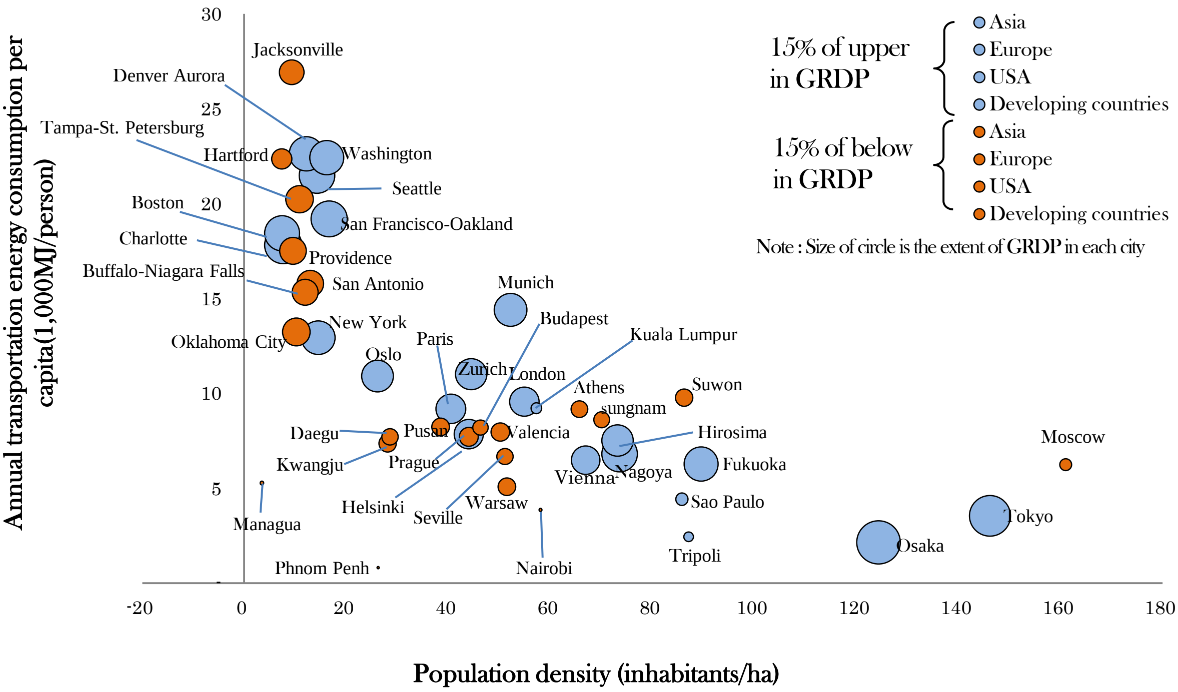

Figure 4-6 Relationship between urban density and urban transportation energy consumption

Finally, Figure 4-6 shows the relationship between urban density and annual transportation energy consumption per capita. Similar to findings of the first part of this chapter and Newman and Kenworthy (1989a, 1989b), I also can ascertain that in denser cities lesser transportation energy is consumed.

In terms of economic level, there is no significant difference in energy consumption in cities in the United States. Overall, in cities in the United States with an extremely low population density and high ownership of passenger car, transportation energy consumption is extremely high regardless of economic level.

In the case of European cities, transportation energy consumption of Munich, Zurich, Oslo, and Vienna, which are cities in the high economic level, is somewhat higher than other cities in Europe. Although population density of European cities is similar, as shown in Figures 4-4 and 4-5, when economic level is higher so to are the modal share of private motorized modes and the number of daily trips. This is likely related to increased opportunities for going out as mentioned the first part of this chapter. Asian cities, such as Japanese cities with a high economic level, possess a denser urban structure, compared to Korean cities that have a lower population density, the amount of transportation energy consumption is smaller. In addition, the propensity of lower private modal share and higher NMM results in a relatively low dependence of private modes. Meanwhile, lower population density and higher private modal share in Korean cities appear to interact with higher transportation energy consumption than Japanese cities, although there is no significant difference in public transit modal.

Lastly, in cities of developing countries, as the economic level of city increases so to does transportation energy consumption becomes (approximately three times). As shown in Figure 4-4 and Table 4-13, if the economic level of a city is high, private modal share is higher and trips for private purpose increases. Based on this finding, I believe that economic level of city influences to modal choice or status of infrastructure development and inevitably impacts the management of traffic demand. Figure 4-4, 4-5, and 4-6 also demonstrate that private mode share, daily trip number, and transportation energy consumption are affected by both urban density and the economic level of the city. This finding is same to the result of the first part of this chapter. Based on these findings, I can conclude that economic level of the city impacts traffic demand, and that private motorized modes, public transport, and how urban structure can be a criteria for understanding how travel behaviors differ by population density.

4.8 Conclusion

Herein, I analyzed the relationship between urban density, travel characteristics, and transportation energy consumption based on the economic level of the cities in the world. Based on this analysis, I can propose that despite similarities in urban density, the economic level of the city influences modal choice and the level of infrastructure development impacts the control of traffic demand. Travel behavior is the result of comprehensive urban-transport activities However, it is certain that the traffic demand of private transportation modes parallels economic development worldwide, such that increases in economic levels leads to higher demands for private transportation modes. I, including researchers and planners, have to establish strategies that can improve the energy consumption and improve urban-transport problems (from a traffic aspect) to mitigate the speed of motorization.

This research showed that person trip data from around the world can be exploited to gain insight into detailed individual travel behaviors, which can in turn be used to estimate transportation energy consumption that takes into consideration the type of vehicle, trip speed, and actual road traffic condition on the trip. Accordingly, I can gain objective results related to actual traffic situations. I showed that there is a relationship between the economic level of a city and urban density, travel characteristics, and transportation energy consumption. The findings of this study suggest new questions regarding how urban-transport characteristics affect individual travel behaviors, and what the next step should be concerning energy consumption, not only estimating transportation energy consumption but also devising ways to reduce it.

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CHAPTER 5

Estimating the efficiency of transportation energy consumption considering urban transportation infrastructure and travel characteristics

Minimizing transportation energy consumption by controlling the increase of the traffic demand and maintaining the level of urban mobility simultaneously is a pressing dilemma for each city. Grasping the impact of the diversity of the urban transport and infrastructure is very important to improve transportation energy efficiency. However, the potential for reducing urban transportation energy consumption has often been ineffectively demonstrated by the diversity of cities. Therefore, the accuracy of evaluating the current efficiency rate of the urban energy consumption is necessary. Nevertheless, quantitative analyses related to the efficiency of transportation energy consumption are scarce, and the research on the current condition of consumption efficiency based on international quantitative analysis is almost nonexistent.

On the basis of this background problem definitions, this research first built a database of the transportation energy consumption of private modes in 119 cities, with an attempt to reflect individual travel behaviors calculated by Person Trip data. Subsequently, Data Envelopment Analysis (DEA) was used as an assessment method to evaluate the efficiency of transportation energy consumption by considering the diversity of the urban traffic features in the world cities. Finally, we clarified the current condition of consumption efficiency by attempting to propose a target values for improving transportation energy consumption.

5.1 Overview of this chapter

In recent years, in each city in the world, people's travel range has expanded due to motorization in parallel with economic development, and the urban structure is changing with suburbanization processes. Moreover, the transportation energy consumption is increasing, resulting in serious urban problems such as air pollution and excessive energy consumption in the urban environment (Nakamura et al., 2004).

New city planning methods and management of technical developments for traffic systems or cutting transportation energy consumption have developed. Since 1970, many planning techniques and research projects have aimed to develop urban structure based on the concept of sustainable development. In Europe, the concept of the compact city is well-received and the urban planning related to constructing efficient urban space is underway and also, in Japan, compact cities have even been specified as a basic policy of urban planning (Taniguchi et al., 2008). Since suburbanization with low population density and increasing trip length are connected with increasing transportation energy consumption (Choi et al., 2011), it is indispensable to control an individual's travel behavior for reducing transportation energy consumption, and it is important to understand the urban-transport factors according to the development of transport infrastructure. Especially, the rail infrastructure in cities contributes to reducing transportation energy consumption in general. However, the size of effects on reducing transportation energy consumption could be different from cities at the condition of rail development. Therefore, it is critically important not only to estimate the transportation energy consumption of a city, but also to clarify how the relationship between transportation energy consumption and individual travel behaviors differ according to the rail development. In order to realize the environmentally sustainable transport (EST), it becomes quite important to mitigate environmental load from the transport sector as well as to maintain the level of mobility.

Because the mobility policies often come into conflict with the environmental ones, the policy decision makers need to find a way to solve the exclusiveness between these two policies (Yoshino et al., 2010). We endeavor to clarify the efficiency of transportation energy consumption from the various urban-transport factors with Data Envelopment Analysis (DEA) cost efficiency model focusing on the transport system. In this context, Feng et al. (2007) and Ahmad et al. (2009) evaluated the energy efficiency in transport sector by using Stochastic Frontier Analysis (SFA) or DEA. Moreover, Yoshino et al. (2010) applied DEA to measure the efficiency of energy consumption at a given level of mobility in public and private transport system. They defined the efficiency of transportation energy consumption with the ratio between energy consumption and the average travel speed of each mode. Nevertheless, these studies used different approaches, they commonly defined the energy efficiency as a ratio of transport index (input) and environmental index (output) or defining mobility with only trip speed is not sufficient enough to reflect the actual travel behavior. The above definitions remain an important problem which does not consider the diversity of transport systems inherent in each city. Obviously the energy efficiency must be influenced by several factors. The weight of each factor could also vary depending on the level of infrastructure development, transport investment and so on. However, most of the existing studies put equal weight on all factors. Meanwhile, the economic level of city has an effect on the relationship between urban density and characteristics of travel behaviors. Choi et al. (2012) clarified that despite similarities in urban density, the economic level of the city influences modal choice and the characteristics of travel behaviors which impacts transportation energy consumption and infrastructure development. However, their research did not consider how the condition of urban transportation infrastructure (i.e., railway system) could have effects on the propensity to transportation energy consumption or its efficiency related to economic feasibility.

Therefore, we defined the efficiency of transportation energy consumption as creating more economical value with less environmental impact of Private Motorized Modes (PMM) by imposing adjusted weights. Here, we consider that GRDP is the economical outcome of the traffic activities generated by people who participate in social economical activities in a city. And, daily trip number of public modes and PMM also can be thought of as the results of traffic activities purposing production activity in a city. In this context, the outputs reflect the economical concept attributed to traffic activities.

5.2 Definition of trip in this research and the estimation method of transportation energy consumption

Basically, the definition of trip and estimation method on transportation energy consumption is same to CHPATER 3. This study is motivated by the trip of private motorized modes (PMM) that directly influence urban transport environment and energy consumption for transport. The trend of private motorized modes is growing as the economy of cities get growing. Also, it is reported that motorization in developing countries are rapid due to their economic growth. Therefore, this study drawn data related to private motorized modes including passenger car, motorcycle, and taxis. The methodology for selecting data is explained in CHAPTER 3.4.1 same as CHAPTER 4.3.1.

This study focused on the large cities in the world and derived transportation energy consumption utilizing person trip data. (Titles of the data for each country are specified at the end *Notes* in CHAPTER 3.) The data dis basically focused on individual trips; however, some of the categories are differ for each country. Therefore, a work was needed to unify definitions and standard for producing transport indexes. The detailed explanation is provided in CHAPTER 3.4.4 same as CHAPTER 4.3.2.

5.3 Target cities and definitions and calculation methods of travel characteristics

This study drew 119 cities with population of 800 thousand or more in 32 countries that publicly providing transport data. The sample size is the largest among other comparative studies done for the cities in the world. The reason for selecting such large sample is to overcome objectivity problems shown in Newman and Kenworthy's research(1989). More detailed information selected cities are provided in CHAPTER 3.3 and Tables 3-4 through 3.7.

As mentioned above, since this study utilizing PT data of the cities in the world, some of the categories are differ depending on the country. Necessarily, the data should have gone through the unifying process for deducing standard for each transport index and definition. More detailed definitions, deducing methods, and references are explained in Table 3-8 and 3-9 same as CHAPTER 4.4.2.

5.4 Classification of cities according to development of urban transportation infrastucture

For grasping the difference of efficiency on transportation energy consumption according to the urban transport and infrastructure, as shown Table 5-2 below, this research classifies the target cities by the development of rail systems with targeting 119 cities in 38 countries.

This research considers mainly two type of railway systems; Metro and Tram, as the classifying standard of urban type. According to literature review, rail transit has come into the spotlight for realizing transit oriented development, providing a good service on transportation, and reducing transportation energy consumption. Many researchers suggested that there is abundant evidence that high quality, grade-separated transit does reduce urban traffic congestion, and that transit improvements can be cost effective investments. Especially, Metro and Tramway systems are represented as major delegates of rail transit that being in charge of urban mobility. According to UITP (2001), Metro is the most efficient transport mode in terms of energy consumption and space occupancy.

In order to transport 50,000 passengers per hour and direction, a metro needs a right-of-way measuring 9 meter in width, whereas a bus would require 35 meter, and cars 175 meter. And also, one kEP (kg Equivalent Petrol) will allow a single person to travel more than 48 kilometer or 38 kilometer by bus, but no more than 19 kilometer by car.

Next, Tramway system (or LRT: Light Rail Transit) is the ideal modes and carrying between 3,000 and 11,000 passengers per hour per direction, and also producing no emissions at street level. Modern traction equipment allows regeneration of braking energy saving. In this way, Metro and Tram systems are have shown that it can reduce the automobile dependence in urban environments and has many positive attributes that benefit a town or city (UITP, 2001).

With this viewpoint, this research attempt to obtain the significance of existence about railway systems from the aspects on economic, travel behaviors and environment impact. Classifying urban type according to the development status of railway system involves this concept. Next, the detail description on Metro, Tramway system and the classification of urban types is explained.

Metro systems are typically located either in underground tunnels or on elevated rails above street level. A tram is a passenger rail vehicle which runs on tracks along public streets and also sometimes on separate rights of way. It may also run as inter-urban, Tram-Train, and/or partially grade separated even in cities. A monorail is a rail-based transportation system based on a single rail, which acts as its sole support and its guide-way. The term is also used variously to describe the beam of the system, or the vehicles traveling on such a beam or track.

Table 5-1 Description of data in this chapter

No	Indicator	Unit	Definition of data
1	Urban Density	inhabitants /ha	Ratio between the population and urban surface area
2	GRDP	$/inhabitants	Ratio between the GRDP of the urbanized area and its population
3	Daily trips by PMM or Public modes	Trip/ day/inhabitant s	Characterized as: -Trips made by persons over 5 years of age who reside in the urbanized area -Trips with at least one extreme (origin and/or destination) inside the urbanized area -All reasons for travel and all transport modes, motorized, or otherwise -Trips on foot or bicycle are not included. -Trips made using several modes are counted as one trip and assigned to a "primary mode".
4	Average trip speed of PMM or Public modes	km/h/trip	With reference to trips defined by indicator 3, including automobiles, motorcycles, and taxis, as PMM, including bus, metro, tram, railway transit on public as Public transport. The actual trip speed is sought.
5	Average trip distance of PMM or Public modes	km/trip	With reference to trips defined by indicator 3, including automobiles, motorcycles, and taxis, as PMM, including bus, metro, tram, railway transit on public as Public transport. The actual distance is sought, not a straight line distance. -In this case, trips extending beyond the urbanized area are considered.
6	Car occupancy	Persons/ vehicle	The average passenger car occupancy rate is an annual rate estimated for the passenger cars over the metropolitan area's entire road network.
7	Average trip duration of Public modes	min/trip	With reference to trips defined by indicator 3, including bus, metro, tram, railway transit on public as Public transport. The actual trip duration is sought.
8	Total metro length	m/1000 inhabitants	The computation of the length of metro in the urban area
9	Total tram length	m/1000 inhabitants	The computation of the length of tram in the urban area
10	Total monorail length	m/1000 inhabitants	The computation of the length of monorail in the urban area
11	Total road length	m/1000 inhabitants	The computation of the length of road in the metropolitan area considers all roads open to public traffic located in the metropolitan area.

From these features, this research categorizes cities into five types of cities by the development level of urban transportation infrastructure: Non-railway, Metro + Tram, Metro only, Tram only, excluding Metro and Tram (including monorail). Here, I are interested in whether or not rail transit is operating in urban area, I focused Metro and Tram as important rail transit systems which have typical characteristics of capacities, form of track and management style. Since, both Metro and Tram are representative modes of rail system in the world and I presume that linkage between Metro and Tram demonstrates higher service level of public modes due to the organic network of rail system that may provide the better accessibility and mobility on travel behavior of person in urban area. Actually after classifying the urban type with the presence or absence of Metro and Tram, the cover ratio of rail system (here I define the ratio total rail length (m) to urban area (ha) as "the cover ratio of rail system (m/ha)") in the urban type *2* is the highest (3.30) among the urban type (Table 5-3). And the order of the cover ratio of rail system is *Type 3, Type 4, Type 5*. Therefore, it is possible to find out that the urban area which the cover ratio of rail system is high generally has the rail network across the rail system. Then, this research considers the relationship between urban density and travel behaviors from the viewpoint on development of urban transportation infrastructure. Finally, I examine how the efficiencies of transportation energy consumption, interacting with economic level, trips by private motorized modes and public modes, are different according to the urban transportation infrastructure.

Table 5-2 City classification according to the urban transportation infrastructure

Urban type	*Type 1*	*Type 2*	*Type 3*	*Type 4*	*Type 5*
Development of urban transportation infrastructure	Non-railway (only Road)	Metro + Tram only	Metro only	Tram only	Excluding Metro, Tram

Table 5-3 Average cover ratio of rail system by urban type

Urban type	*Type 1*	*Type 2*	*Type 3*	*Type 4*	*Type 5*
The cover ratio of rail system	0.00	3.30	0.82	0.36	0.24

5.5 Relationship between urban density and travel characteristics according to the urban transportation infrastructure

This research first presented relationship between urban density and travel behaviors on PMM and Public modes according to the urban transportation infrastructure. Specifically, we focused on the features of variables indicating travel behaviors which included in estimation of transportation energy consumption (trip number, trip speed and trip length) as above Figure 5-1 to 5.

Figure 5-1 shows that higher urban density yields fewer daily trips number on average. Especially, in the case of rail systems in Type 2 and Type 3, trip number is quite low (2.81 trips/day/person in Type 2, 2.68 trips/day/person in Type 3) compared to other cities. This shows that trip number in Type 2 rail system is the lowest under the highest urban density (60.2 inhabitants/ha). Next, Figure 5-2 reveals that higher urban density is favorable for shorter trips by PMM. Particularly, Type 2 rail system under the highest urban density generally makes trip length shorter (10.7 km/trip). In this context, Giuliano and Dhiraj (2003) built the regression model interpreting daily trip number and average trip distance in cities by applying the characteristics of the socio-economic and urban density. Their result shows that the urban density has significant effect on travel behaviors and there is a divergence of results. In general, the daily trip number depends on the urban scale. The larger the urban area is, the less daily trip number is generated.

In addition, the trip distance is substantially significant with urban density, and the denser the urban density is, the shorter the trip distance is.

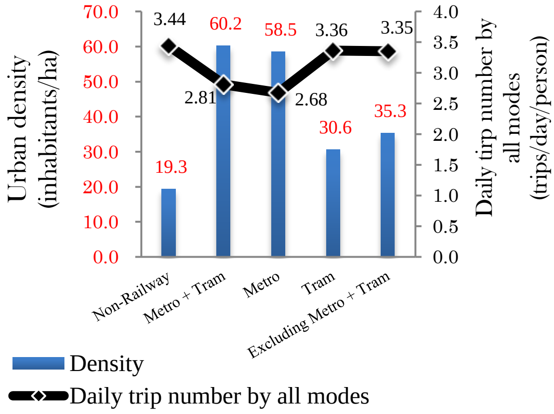

Figure 5-1 Relationship between density and daily trip number

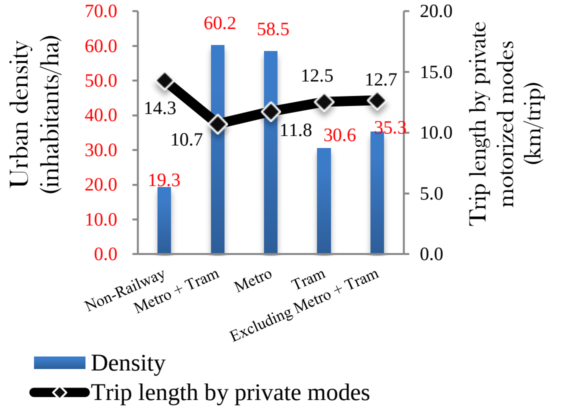

Figure 5-2 Relationship between density and trip length by private motorized modes

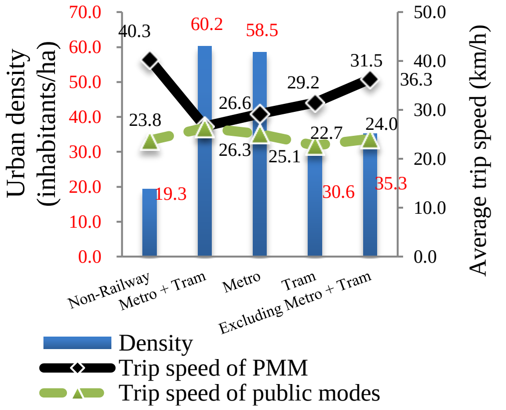

Figure 5-3 Relationship between density and average speed of PMM, public modes

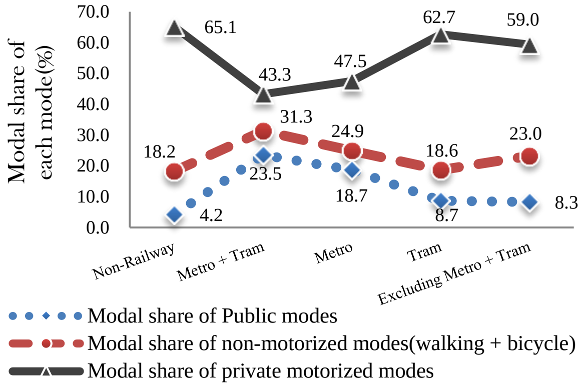

Figure 5-4 Modal share of all modes

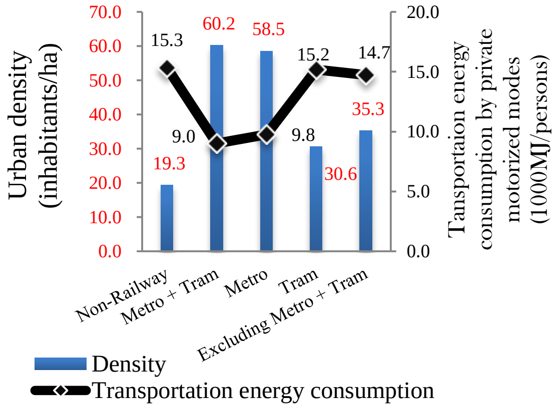

Figure 5-5 Relationship between density and transportation energy consumption

Figure 5-3 shows that trip speed of PMM and public modes. In general, speed of PMM is slower and speed of public modes is faster under denser urban structure. Especially, the feature of Type 2 in which trip speed of PMM is the slowest (26.6 km/h) and speed of public modes is the fastest (26.3 km/h) is outstanding. These results from Figure 5-3 intensely show that denser urban structure influences travel behavior on PMM and public modes. Also, it could be conjectured that there is a relationship between denser urban structure and the travel pattern for public transport such as metro or tram.

In this context, Figure 5-4 shows the ratio of the modal share according for PMM, public modes and Non-motorized modes (NMM). From here, it is possible to figure out that modal choice for public modes and NMM are often made under the urban condition of having a railway system. Especially, the condition of *Type 2* restrains the use of PMM but revitalizes the use of public modes and NMM.

Therefore, it could be conjectured that development of as established rail network such as link of

Metro and Tram would absorb travel demands. And also, depending on the development of railway system, space management could be properly maintained for pedestrians or bicycle riders. Figure 5-4 demonstrates that denser urban structure represses the usage of passenger cars and promotes higher demand for public modes and walking, bicycling. In addition, the specific effect of denser urban structure appears under *Type 2* rail system. Considering all relations between urban density and travel behaviors above, transportation energy consumption is lower under denser urban structure with an established rail system such as *Type 2* or *Type 3* as shown in Figure 5-5.

5.6 Estimation on efficiency of transportation energy consumption

5.6.1 Definition on efficiency of transportation energy consumption

The current research defines the efficiency of transportation energy consumption as creating more economical value with less environmental impact of PMM. The efficiency in this chapter is considered from the two aspects of economic level and travel characteristics. In DEA modeling, the efficiency can be obtained from the ratio between input variables and output variables as explained below 5.5.2. Input variables are positioning in denominator and output variables are in numerator. Here, I consider transportation energy consumption, GRDP, Daily trip number of Public modes and Private Motorized Modes (PMM) as major variables for analysis. GRDP generally shows the economic status of the city. Meanwhile, it is possible to think on reflection that GRDP is also the economical outcome of the traffic activities generated by people who carry out social economical activities in a city. And, daily trip number of public modes and PMM also can be thought on reflection as the results of traffic activities purposing production activity in a city. In this context, the output variables in numerator are involving the economical concept attributed to traffic activities.

Whereas, the factor of transportation energy consumption can be utilized as an index appears automobile dependence. Therefore, the efficiency of transportation energy consumption in the current research can be interpreted as a meaning that how automobile dependence acts on the economical activities of the city or whether automobile dependence is effective on production activities. Consequently, higher efficiency on energy use of transport means that creating more economical value with less environmental impact of PMM. This research attempted to observe how much GRDP and trips by private motorized modes and public modes are created by transportation energy consumption of PMM which means the result from the production activity in a city. The maximum efficiency is *1*, which indicates the city creating comparatively most multi-value with less transportation energy consumption of PMM.

5.6.2 Estimation model in the current chapter (Data Envelopment Analysis (DEA))

Data Envelopment Analysis (DEA) is a nonparametric method in operations research for the estimation of efficiency. It is used to empirically measure the efficiency of decision making units (DMUs). This allows a best-practice relationship between multiple outputs and multiple inputs to be estimated. DMU is the subject of evaluation and the efficiency of DMU is calculated by the ratio scale of (*output / input*). If there are many entities with similar results, it is possible to make a comparison between them with the relative magnitude of the ratio scale. In addition, evaluation by a changeable weight that ignores the unit of individual variable is possible.

However, DEA does not provide a general relationship relating output and input. Furthermore, this evaluation method is not for absolute evaluation of efficiency but is for relative comparison analysis between entities. Therefore, in carrying out DEA on efficiency of transportation energy consumption, One needs to understand the theoretical causal relationship between urban-transportation factors on reading analyzed results. Thus, this research utilizes DEA as only an estimation method for comparative analysis on energy efficiency.

The Charnes Cooper Rhodes (CCR) model can be quoted as the most basic models of DEA. DMUs has a number of N, and when there are m of individual inputs and s of outputs, a virtual input and output defined by equations 5-1 and 5-2 below. Here, put a weight that it can be advantageous to DMUs on the input and output. However, the efficiency is represented by a *virtual output / virtual input*, and maximum weight is *1* so that it does not take a negative value. The following formula is a fractional programming equation. The optimal solution obtained from here is *(v *, u *)*, and the case of θ^* is the objective function. If $\theta^*=1$: MDU_0 is effective, if $\theta^*<1$: MMU_0 is ineffective. The weights are obtained from each input value in the entire input on denominator, and it is called weighted input value. In the same way, the value on numerator of DMU is called weighted output value.

A virtual input $\Theta_i = v_1 \times \text{input } 1 + v_2 \times \text{input } 2 + \cdots + v_m \times \text{input } m$ **(Eq. 5-1)**

A virtual output $\Theta_o = u_1 \times \text{output } 1 + u_2 \times \text{output } 2 + \cdots + u_s \times \text{output } s$ **(Eq. 5-2)**

Objective function $$\theta^* = \frac{u_1 y_1 + u_2 y_2 + \cdots + u_s y_s}{v_1 x_1 + v_2 x_2 + \cdots + v_m x_m}$$ **(Eq. 5-3)**

$$\frac{u_1 y_{1j} + u_2 y_{2j} + \cdots + u_s y_{sj}}{v_1 x_{1j} + v_2 x_{2j} + \cdots + v_m x_{mj}} \leqq 1 \quad (j = 1, \ldots, n)$$ **(Eq. 5-4)**

Constraints $$v_1, v_2, \ldots v_m \geqq 0$$ **(Eq. 5-5)**

$$u_1, u_2, \ldots u_m \geqq 0$$ **(Eq. 5-6)**

5.6.3 Estimation of the efficiency of transportation energy consumption

The analysis in this chapter estimates the efficiency of transportation energy consumption. The efficiency of transportation energy consumption means the ratio between the combination of GRDP, trips by PMM, public modes and the transportation energy consumption of Private motorized modes. For this, a changeable weight was considered to variables on input and output for estimating by DEA. The *efficiency = 1.0* means a Frontier that DMU is relatively the most desirable city in this research related to efficiency of transportation energy consumption from the energy consumption of PMM. As mentioned above, the efficiency from DEA does not show the relationship between urban-transportation factors. Therefore, we clarified a relationship between urban density and travel characteristics before utilizing DEA.

Based on the findings above Figure 5-1 to 5-6, I next examine the efficiency of transportation energy consumption with considering whole target cities. And then, the result was classified according to the rail systems as shown Table 5-4, 5-5 and Figure 5-6.

Table 5-4 Average efficiency of transportation energy consumption

Urban type	*Type 1*	*Type 2*	*Type 3*	*Type 4*	*Type 5*
Average efficiency of transportation energy consumption	0.2106	0.3287	0.3086	0.1806	0.2110

Table 5-5 Efficiency on transportation energy consumption of 119 cities

Urban Area	Type	Efficiency of transportation energy consumption	Transportation energy consumption	Urban Area	Type	Efficiency of transportation energy consumption	Transportation energy consumption	Urban Area	Type	Efficiency of transportation energy consumption	Transportation energy consumption
Charlotte	1	0.229	17,816	Vienna	2	0.405	6,483	Inchon	3	0.237	7,372
Houston	1	0.168	18,692	Amsterdam	2	0.251	7,591	Daejeon	3	0.225	6,425
Indianapolis	1	0.164	19,725	Rotterdam	2	0.182	9,428	Pusan	3	0.242	8,231
Milwaukee	1	0.189	15,596	Lyon	2	0.212	10,518	Kwangju	3	0.216	7,359
Columbus	1	0.061	39,980	Rome	2	0.156	12,156	Suwon	3	0.177	9,781
Kansas City	1	0.160	21,534	Brussels	2	0.167	11,828	Athens	3	0.161	9,169
Austin	1	0.166	18,045	Lille	2	0.189	10,754	Daegu	3	0.194	7,714
Nashville-Davidson	1	0.152	23,291	Berlin	2	0.279	7,874	Sungnam	3	0.290	8,613
Ulsan	1	0.198	9,785	Lisbon	2	0.232	6,193	Sao Paulo	3	0.303	4,428
Orlando	1	0.170	17,618	Prague	2	0.503	7,706	Kuala Lumpur	3	0.141	9,221
Cincinnati	1	0.162	20,586	Valencia	2	0.146	7,965	Lima	3	0.881	2,348
Phoenix	1	0.166	17,495	Warsaw	2	0.524	5,077	Damascus	3	0.938	1,548
Louisville	1	0.173	17,737	Budapest	2	0.360	8,197	Seattle	4	0.153	22,623
Rochester	1	0.177	17,288	Moscow	2	0.495	6,251	Hiroshima	4	0.225	7,524
Honolulu	1	0.196	13,552	Bucharest	2	0.448	6,713	Zurich	4	0.252	11,013
Norfolk	1	0.122	26,343	Cairo	2	0.302	7,747	Portland	4	0.149	17,287
Oklahoma City	1	0.202	13,237	Nagoya	3	0.314	6,812	New Orleans	4	0.145	20,240
Providence	1	0.158	17,510	Washington	3	0.149	21,476	Memphis	4	0.115	22,357
San Antonio	1	0.164	15,790	Boston	3	0.181	18,437	Turin	4	0.198	8,447
Jacksonville	1	0.130	26,915	Fukuoka	3	0.280	6,279	Melbourne	4	0.139	17,002
Dubai	1	0.165	11,005	New York	3	0.196	12,931	Manchester	4	0.189	10,222
Hartford	1	0.106	22,352	Atlanta	3	0.154	20,591	Denver	5	0.153	22,422
Tripoli	1	0.477	2,445	Chicago	3	0.197	14,113	Dallas	5	0.161	18,703
Chengdu	1	0.251	1,747	Los Angeles	3	0.178	16,217	Minneapolis -St. Paul	5	0.108	30,467
Ho Chi Minh	1	0.135	8,252	Sendai	3	0.255	7,116	Salt Lake City	5	0.199	14,041
Hanoi	1	0.239	899	Kyoto	3	0.401	3,397	Detroit	5	0.172	17,229
Jakarta	1	0.266	4,971	Cleveland	3	0.083	33,645	Chiba	5	0.416	4,892
Managua	1	0.331	5,276	Kobe	3	0.332	4,238	San Diego	5	0.151	19,691
Nairobi	1	0.096	3,857	Baltimore	3	0.130	21,476	St. Louis	5	0.138	20,056
Phnom Penh	1	1.000	817	Miami	3	0.156	15,488	Pittsburgh	5	0.103	22,706
Osaka	2	1.000	2,148	Yokohama	3	0.396	5,304	Kitakyushu	5	0.183	8,298
Tokyo	2	0.796	3,548	Saitama	3	0.458	4,001	Copenhagen	5	0.201	10,306
San Francisco	2	0.176	19,197	Singapore	3	0.374	8,139	Kawasaki	5	0.666	3,305
Munich	2	0.189	14,397	Hong Kong	3	1.000	2,562	Sacramento	5	0.127	21,761
Oslo	2	0.245	10,908	Glasgow	3	0.177	11,084	Stuttgart	5	0.169	13,514
Philadelphia	2	0.162	18,738	Bilbao	3	0.184	6,942	Tampa	5	0.134	20,230
Paris	2	0.246	9,187	Seoul	3	0.846	2,438	Buffalo	5	0.163	15,331
Helsinki	2	0.352	7,851	Madrid	3	0.195	10,719	Seville	5	0.150	6,670
London	2	0.235	9,560	Newcastle	3	0.199	8,956	Manila	5	0.231	5,298
Sapporo	2	0.294	6,191	Barcelona	3	0.196	6,934				

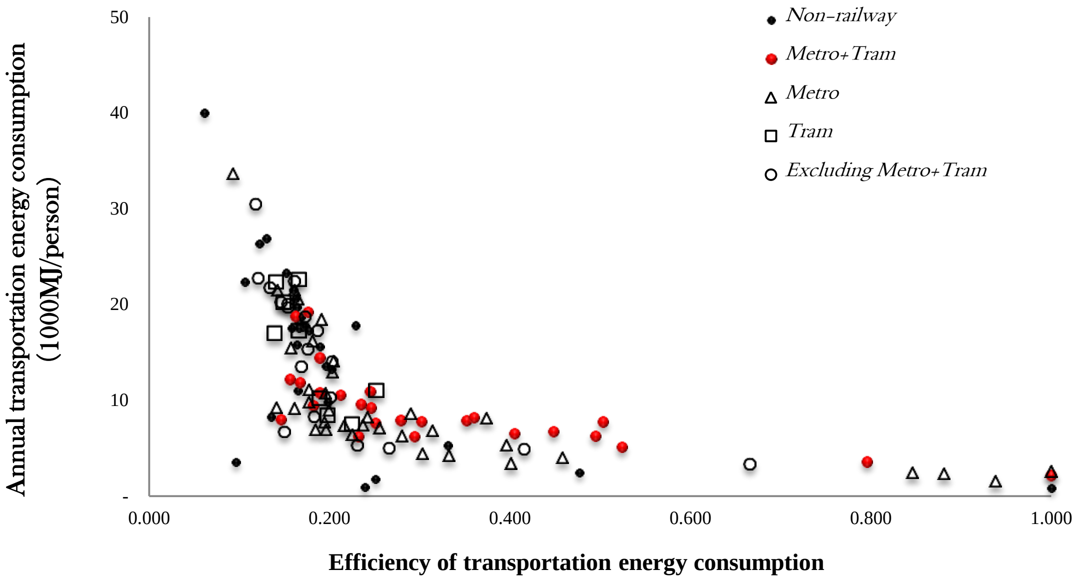

Figure 5-6 Relationship between efficiency of energy consumption and transportation energy consumption

Table 5-6 Characteristics on travel behaviors, efficiency of energy consumption and transportation energy consumption

Variables		Non-Railway	Metro and Tram	Metro	Tram	Excluding Metro and Tram
Urban density (inhabitants/ha)		19.3	60.2	58.5	30.6	3.3
Daily trip number(trips/day)		3.44	2.81	2.68	3.36	3.35
Average trip distance of PMM (km/trip)		14.3	10.7	11.8	12.5	12.7
Average trip speed (km/h)	*PMM*	40.3	26.3	26.6	29.2	31.5
	PUB	23.8	26.3	25.1	22.7	24.0
Modal Share (%)	*PMM*	65.1	43.3	47.5	62.7	59.0
	PUB	4.2	23.5	18.7	8.7	8.3
	NMM	18.2	31.3	24.9	18.6	23.0
Transportation energy consumption (MJ/person/year)		15,340	9,008	9,764	15,190	14,731
Energy efficiency		0.2106	0.3287	0.3086	0.1806	0.2110

Figure 5-6, and Table 5-5 show the results of DEA analysis on the efficiencies of 119 cities in Asia, Europe, USA and developing countries. And the result of DEA is classified by the development of the rail systems. As shown in Figure 5-6, an inverse relation between the energy efficiency and the energy consumption is observed. The efficiency ranges from 0.061 (Columbus) to 1 (Osaka, Hong Kong, Phnom Penh). Generally, the efficiency in cities of the USA of Type 1which have low density is low.

Meanwhile, cities having denser urban structure, longer railway, combination rail systems and high modal share by public modes such as Tokyo, Fukuoka, Vienna, Hong Kong, Lima etc. are showing higher efficiencies of transportation energy consumption. Table-5-5 reveals that the average efficiency of transportation energy consumption is 0.3287 (Type 2), 0.3086 (Type3), 0.2110 (Type5), 0.2106 (Type1) and 0.1806 (Type 4) in the order of the level of the rail system, showing high efficiency.

In Figure 5-6, the urban types having rail systems broadly indicate higher efficiency on transportation energy consumption than Type 1 having non-rail system. The efficiencies of Type 2 having Metro + Tram and Type 3 having Metro are particularly outstanding. Here, Type 1 and Type 5 including many US cities in which urban density is quite low show almost same efficiency.

In Figure 5-6 and Table 5-6 one of the urban type that shows the lowest efficiency next to Type 4 is Type 1 with no rail system. From Figure 1 to 5, the highest trip generation, the longest trips, the slowest trip speed of public modes and the highest energy consumption are observed for Type 1. Choi et al. (2011) demonstrated that the longer trip, the more trips generation under lower density such as Type 1 including the US cities. And also, it is possible to deduce that the efficiency of transportation energy consumption does not become effective under low urban density on the contrary to Type 2 and Type 3 including DUMs which the efficiency is 1 as shown Figure 5-6. Meanwhile, Phnom Penh (1.000), Tripoli (0.477), Managua (0.331) in Type 1 show relatively high energy efficiency as shown in Table 5-5 even if they are non-railway type for which the common trend of economic level (GRDP) in these cities is quite low. From this result, it is possible to conjecture that people have to rely on the public modes due to less car ownership under low economic status. In this context, the high modal share of the public transport in the above cities could affect the result that the energy efficiency is high due to the adjustable weight of DEA model. Meanwhile, the efficiency of Type 4 is the lowest relative to other the rail systems and Type 1. According to Figure 5-3, 4 and 5 as shown above, Type 4, with only tram, shows the slowest trip speed of the public modes, the highest modal share of PMM and transportation energy consumption among urban types having a rail system even though the rail system is constructed. Especially, the urban density (30.6 inhabitants/ha) of Type 4 is the lowest among the urban types having the rail system. This might mean that the rail system under low density does not show the correlation between a rail network and restraining usage, energy consumption of PMM.

5.7 Conclusion

This research built a database of 119 cities concerning transportation energy consumption of the private motorized modes, and it reflects individual travel behaviors calculated by Person Trip data. In addition, we established the relationship between urban density and travel characteristics before utilizing DEA that considers the diversity of urban-transport features. Consequently, we clarified that denser urban structure, with well-maintained railway system (such as Metro + Tram), could divert the private vehicle users to the public transport, hence decrease the transportation energy consumption, and encourage NMM. Therefore, it seems that denser urban structure and well-constructed railway systems have meaningful relationship with realizing higher efficiency of transportation energy consumption.

The results provide practical and reliable information related to reducing transportation energy consumption through the propensities of travel behaviors and efficiencies on energy consumption. Furthermore, understanding the relations between urban density and travel characteristics according to the level of railway systems will be invaluable for measures to reduce energy consumption in urban development planning.

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CHAPTER 6

Conclusions

6.1 Brief summary

CHAPTER1

In this chapter a general introduction regarding the research backgrounds, scope of research, and expected contributions of the research are discussed. This part mainly explains why we need to take a grasp on the urban-transport programs resulted from motorization in the world and find the balance between economic development and sustainable development. And also, it is strongly recommended how this research should be utilized for urban-transport planning in the future while introducing the basic philosophy of this study.

CHAPTER 2

A widespread study is focused on transportation energy consumption covering analysis related to urban density, travel behavior, economical factors, rail transit, urban-transport policies. They are mainly comparative studies on statistical indicators and data such as, interactions within a social economy, travel characteristics, urban density and so on. Mostly, they are targeting macroscopic range. On the basis this research is going to focus on the following aspects:

(1) Study on the comparability of basic statistic data's and indicators. This research addresses Person Trip (PT) data and comprehensive statistical data on urban-transport in various cities of the world. Since comparative research utilizing a database on a worldwide scale in not yet established, methods to ensure the comparability of indicators as well as data attainability will be ensured.

(2) Certain comparable conditions, such as the load of transportation energy consumption, are required in the comparison of characters on transportation energy consumption.

(3) Study on the factors influencing transportation energy consumption and it's the sensitivity. Affected by different size groups, in the macro (urban) and micro (individual) level, transportation energy consumption should be studied in different collective groups.

CHAPTER 3

In this chapter, I conducted a database of cities of the world for transportation energy consumption of private motorized vehicles using information from travel behaviors calculated from Person Trip (PT) data. The data came from public sources in 119 metropolitan areas in 38 countries. The constructed database provides practical and reliable information, including travel behavior. The data confirms that each country has certain differences in the relationship between individual travel behaviors, the dependence on private automobiles and urban density. Additionally, understanding the relations between urban density and travel characteristics will be invaluable for measures to reduce energy consumption in urban development planning. The major results from the database are shown below.

- *Urban density and Transportation energy consumption* — A negative correlation
- *Urban density and Passenger car ownership* — A negative correlation

- *Urban density and Modal share of Private Motorized Modes* — A negative correlation
- *Urban density and Average Daily trip number* — A negative correlation
- *Urban density and Average trip Distance by PMM* — A negative correlation

These findings demonstrate that many factors which affect transportation energy consumption (private car ownership, average daily trip number, average modal share of private motorized modes and average travel length on private motorized modes) has a relationship with the urban structure which was also an indicator of the population density in each area.

CHAPTER 4

In this chapter, I analyzed the relationship between urban density, travel characteristics, and transportation energy consumption based on the economic level of the cities in the world by utilizing a discriminant analysis considering the relationship between urban density and transportation characteristics. Based on the results of the analysis we examined the correlation between urban density and transportation energy consumption by economic level. Analysis showed that the relationship between urban density and travel characteristics differs by the city's economic level. Additionally, the more economic development, the clearer the correlation between urban density, travel characteristics and transportation energy consumption becomes.

Based on this analysis, I can propose that despite the similarities in an urban density, the economic level of the city influences the modal choice and the level of infrastructure development which impacts the control of traffic demand. Travel behavior is the result of comprehensive urban-transport activities, making it difficult to determine the key factor impacting transportation energy consumption. However, it is certain that the traffic demand of private transportation modes parallels economic development worldwide, such that increases in economic levels leads to higher demands for private transportation modes.

In addition, I demonstrated the correlation between urban density and the characteristics on travel behaviors by PMM becomes stronger with cities of higher economic development, suggesting maximum R=0.9 correlation, of the Top of 40 cities by GRDP. This therefore, is meaning that the correlation between urban density and automobile dependence is strong based on cities of higher economic development, implying that the cities have a spread urban structure due to the motorization accompanying with economic development.

CHAPTER 5

In this chapter, I grasped the causal relationship between urban density and travel characteristics before utilizing Data Envelopment Analysis (DEA) considering the diversity of urban-transport features. In order to analysis this, I defined the efficiency of transportation energy consumption as creating more economical value with less environmental impact of Private Motorized Modes (PMM) by imposing adjusted weights. Here, I consider that GRDP is the economical outcome of the traffic activities generated by people who participate in social economical activities in a city. And, daily trip number of public modes and PMM also can be thought of as the results of traffic activities purposing production activity in a city. In this context, the outputs reflect the economical concept attributed to traffic activities.

Consequently, I clarified with my research that denser urban structure, with well-maintained railway systems (such as Metro + Tram), could refrain the use of private vehicles and encourage public transport along with NMM to reduce transportation energy consumption. It has also been proven that the combination of transport systems also show higher efficiency where average energy consumption of Metro alone is 0.329 compared to a combined metro and tram system having consumption rates of 0.309. In this light it can be said that a well-coordinated transportation infrastructure is crucial in an urban infrastructure.

The results provide practical and reliable information for reducing transportation energy consumption through the propensities of travel behaviors. And also, understanding the relations between urban density and travel characteristics of railway systems will be invaluable for planning an energy efficient urban structure.

6.2 Closing remarks

The overall objective of this thesis is to describe the development of a framework which can be used to estimate the transportation energy consumption and to grasp the travel patterns influenced by urban density or transportation infrastructure targeting various cities in the world. This challenge aims on diagnosing how the automobile dependence show different features according to urban conditions which includes demography, economic level, urban density, rail transit. Consequently, it was possible to obtain that the results belong to a mainstream of the current research related to urban-transport planning. For example, a superiority of denser urban density or the importance of the developing rail transit from the aspects of restraining automobile use, and also a necessity of transferring travel behaviors, through the integration of public modes or offering better quality of public service, from private modes to public modes for sustainable transport in the future. These results are quite importantly introduced in planning initiatives or strategies on sustainable urban-transport development.

However, I wonder for whom these findings are to be used? And, is it true for sustainable development? Who are the policies for sustainable society for? This means that the policy estimation is different based on the point of view (according to the person who establishes policy or receives it). The results in this study may be in favor to policy maker due to the macro viewpoint on urban development. Mees (2009) mentioned it in his book that the real problem with urban-transport policy such as road pricing, as Singapore has demonstrated, is that it makes car travel more attractive for those who can afford to pay the charge. Therefore, policies should focus on alternative measures that also benefit the wealthy motorists as well. Density debate is also in the same context. As Lowe (2005) said, some people understand the attractiveness of leafy suburb rather than denser urban space with population. From this, I can find out that the urban-transport policy can offer different incentives, or sometime inconvenience, according the condition of person who is a policy maker or receiver or in a social position. In this way, it is necessary to rethink the major current stream of research on sustainable development, and I have to make strategies which both sides (policy/ planning maker and receiver) can be understood and satisfy, also known as a "win-win strategy".

This research has not attempted to estimate and consider in detail individual benefits from the aspect of sustainability. For this, I plan to determine the effects or benefit on the individual level by urban-transport policy for sustainability, not only in the macro level, such as urban or region, country for satisfying both side of person and society.

APPENDIX

- Table A — Literature Review related to the current research
  (Refer to Figure 2-1 showing the result on organizing major keywords in the current research)
- Table B — Database on the characteristics of urban-transport in the world
  (Korea, Japan, Wealthy Asian, USA, Europe, Developing countries)

Table A. Literature Review related to the current research (56)

Author (year)		Newman, Kenworhty (1989a)	Newman, Kenworhty (1989b)	Newman, Kenworthy (1996)	Kenworthy, Laube (1999)	Loo H., (2010)	Givoni, Rietveld (2007)	Podobnik (2002)	Khanna (2011)	Litman (2007)	Banister (2002)	Eom, Schipper (2010)	McCann (2001)	Giuliano, Dargay (2006)	Laube (1999)
International comparison		●	●	●	●							●			
Development of Index															
Urban Structure	*Demography*												●		
	Urban density	●	●	●	●	●		● *Urban sprawl*		●	●		●		●
	Mono-centric														
	Poly-centric			●											
	Mixed land use	●	●	●	●	●				●	●				
Travel Behaviors	*Trip number*														
	Trip length (Commuting)				●										
	Trip duration		●		●										
	Trip speed														
	Car ownership	●	●	●	●									●	
	Ridesharing														
	Mobility														
	Accessibility						●								
Trip Purpose	*Private*														
	School, Commuting														
Transportation Infrastructure	*Road (Network)*				● (*Expenditure*)								●		
	Road Congestion		●							●					
	Rail	●	●	●	●	● (*Station*)	● (*Station*)		● (*Metro*)	●					
	Multi-modal system														
Economic level (City or Individual)		●	●									●			
Travel cost (including fuel price)		●								●			●	●	
Urban Policies	*Urban planning (e.g. TOD)*			●	●		● (*TOD*)	●							
	Public transport		●												
	Regulations														
	Fuel consumption		●									●			
Others		*Collecting data*	*Collecting data*	*Collecting data*			*Parking space around station*					*CO_2*			

Author (year)		Cervero, et al., (2002)	Morimoto, Fukuike (2002)	Chen, et al., (2008)	Su (2011)	Bento, et al., (2005)	Karathodoro et al., (2010)	Small, Dender (2007)	Coevering, Schwanen (2006)	Richadson, Gordon (2001)	Holz Rau,C (1997)	Cervero (1996)	Taniguchi, et al., (2008)	Schwanen, et al., (2004)	Chikanari, et al., (2003)
International comparison							●		●						
Development of Index															
Urban Structure	*Demography*				●				●						
	Urban density	●	●	●	●	●	●	●	●	●	●	●	● (*Urban shape*)	● (*Inner area*)	
	Mono-centric									●					
	Poly-centric										●		●	●	
	Mixed land use	●									●	●			
Travel Behaviors	*Trip number*														
	Trip length (Commuting)					●	●	●		●	●	● (*Commuting*)			
	Trip duration								●						●
	Trip speed						●			●					●
	Car ownership								●			●			
	Ridesharing														
	Mobility														
	Accessibility														
Trip Purpose	*Private*														
	School, Commuting														
Transportation Infrastructure	*Road (Network)*		●												
	Road Congestion														
	Rail					●									
	Multi-modal system														
Economic level (City or Individual)									●						
Travel cost (including fuel price)					●				●						
Urban Policies	*Urban planning (e.g. TOD)*	●													
	Public transport														
	Regulations														
	Fuel consumption						●								
Others													CO_2		

Author (year)		Mindali et al., (2004)	Lee (2005)	Giuliano, Dhiraj (2003)	Schimek (1996)	Shaldon, et al., (2009)	Hamilton (1982)	White (1988)	Taniguchi (1999)	Lefevre (2010)	Zashariadis, Kouvaritakis (2003)	He, et al., (2005)	Parshall, et al., (2010)	John, et al., (2005)	Akerman (2011)
International comparison		●		●							●				
Development of Index		●													
Urban Structure	*Demography*			●					●						
	Urban density	●	● (*Spatial structure*)	●	●					●					
	Mono-centric														
	Poly-centric														
	Mixed land use	●													
Travel Behaviors	*Trip number*			●											
	Trip length (Commuting)			●	●	●	● (*Commuting*)								
	Trip duration							● (*Commuting*)							
	Trip speed														
	Car ownership				●				●						
	Ridesharing					●									
	Mobility		●												
	Accessibility									● (*Rail, Bus*)					
Trip Purpose	*Private*														
	School, Commuting														
Transportation Infrastructure	*Road (Network)*	●													
	Road Congestion	●													
	Rail														● (*High speed rail*)
	Multi-modal system														
Economic level (City or Individual)				●	●				●						
Travel cost (including fuel price)											●	●		●	
Urban Policies	*Urban planning (e.g. TOD)*														
	Public transport	●	●	●						●					
	Regulations														
	Fuel consumption					●						●	●		
Others											*CO_2, Freight*	*Oil demand*	*Industry*	*Public funding, Politic support*	*CO_2, Freight*

Author (year)		Milford, et al., (2010)	Qipeng, et al., (2009)	Koushki (1991)	Kim, et al., (2007)	Mackett, Sutcliffe (2003)	Loo, et al., (2010)	Ida, et al., (2001)	Morrow, et al., (2010)	Reddy, D'Sa (2000)	Poudenx (2008)	Walmsley (2006)	Vold (2005)	Albalate, Bel (2010)	Sung, Oh (2011)
International comparison						●	●				●(case study)			●	
Development of Index															
Urban Structure	*Demography*			●	●		●							●	
	Urban density														●
	Mono-centric														
	Poly-centric														
	Mixed land use					●	●						●		●
Travel Behaviors	*Trip number*			●									●		
	Trip length (Commuting)												●		
	Trip duration												●		
	Trip speed												●		
	Car ownership			●							●				
	Ridesharing						●				●				
	Mobility														
	Accessibility										●				
Trip Purpose	*Private*														
	School, Commuting														
Transportation Infrastructure	*Road (Network)*														
	Road Congestion					●									
	Rail	●			● (*LRT*)	●(*Metro,LRT*)	●	●							●(*Station*)
	Multi-modal system														
Economic level (City or Individual)														●	
Travel cost (including fuel price)				●											
Urban Policies	*Urban planning (e.g. TOD)*				●		● (*TOD*)					●			● (*TOD*)
	Public transport					●	●				●(*Service level*)			●(*Demand*)	
	Regulations								●(*Fuel tax*)		●		●(*Fuel tax*)		
	Fuel consumption								●						
Others		*CO_2, Materials on rail structure*			*Modal choice*	*Framework on evaluating rail system in the world*			*GHG emission*		*Evaluating policies on urban transportation*	*Planning initiatives in the US*			

Table B-1 Database on the current research in the region of Korean, Japan and Wealthy Asian: (27cities)

No	Nation	Urban	Population	Urbanized Area	Urban Density	GRDP	Number of daily Trips	Trip by PMM	Trip by PUB	Trip by NMM	Private motorized mode	Public Transport	Non-motorized mode
unit			persons	Ha	inhabitants /ha	$/person	Trips/day *capita	Trips/ day	Trips/ day	Trips/ day	%	%	%
1	Korea	Seoul	10,297,004	60,540	170.1	20,371	2.42	0.60	0.88	0.74	24.7	36.2	30.4
2	Korea	Pusan	3,657,840	76,443	38.5	13,086	2.53	0.86	0.78	0.01	34.0	30.9	31.7
3	Korea	Daegu	2,525,836	88,446	28.6	11,201	2.54	0.98	0.49	0.97	38.5	19.5	38.2
4	Korea	Inchon	2,632,178	99,412	36.5	15,296	2.50	0.88	0.64	0.88	35.3	25.6	35.3
5	Korea	Kwangju	1,408,106	50,141	28.1	12,776	2.53	1.09	0.49	0.86	43.2	19.4	34.1
6	Korea	Daejeon	1,462,535	53,978	29.5	13,318	2.52	1.05	0.40	0.40	41.8	15.7	15.7
7	Korea	Ulsan	1,095,105	105,710	14.6	38,044	2.54	1.10	0.35	0.95	43.4	13.8	37.2
8	Korea	Suwon	1,046,591	12,110	86.2	12,595	2.66	1.17	0.56	0.71	43.9	21.1	26.8
9	Korea	Sungnam	992,758	14,180	70.1	10,550	2.77	1.19	0.95	0.52	43.1	34.3	18.8
10	Japan	Tokyo	8,499,697	62,149	146.1	71,052	2.09	0.32	0.74	1.05	14.5	33.4	47.8
11	Japan	Yokohama	3,579,628	48,667	108.4	34,418	2.01	0.57	0.71	0.83	25.8	32.4	37.7
12	Japan	Osaka	2,628,811	25,199	124.3	79,573	1.97	0.21	0.21	1.24	9.6	9.6	56.5
13	Japan	Nagoya	2,215,062	34,270	73.6	54,184	2.11	0.88	0.33	0.82	40.0	15.1	37.0
14	Japan	Sapporo	1,880,863	112,121	75.4	36,289	1.96	0.93	0.36	0.80	42.1	16.3	36.4
15	Japan	Kobe	1,525,393	25,199	76.1	38,705	1.97	0.48	0.21	0.92	21.7	9.7	41.9
16	Japan	Kyoto	1,474,811	82,784	98.3	39,753	1.92	0.46	0.17	1.07	20.9	7.8	48.6
17	Japan	Fukuoka	1,401,279	47,053	89.5	49,258	2.18	0.78	0.18	0.50	35.4	8.4	22.6
18	Japan	Kawasaki	1,327,011	17,957	104.5	33,287	1.95	0.42	0.85	0.89	18.9	38.4	40.6
19	Japan	Saitama	1,176,314	11,587	101.5	32,441	2.14	0.59	0.55	0.96	26.9	24.9	43.7
20	Japan	Hiroshima	1,154,391	95,734	73.2	41,868	2.14	0.88	0.21	0.73	40.0	9.5	33.1
21	Japan	Sendai	1,025,098	79,387	56.9	40,397	2.04	1.02	0.26	0.71	46.4	11.6	32.1
22	Japan	Kitakyushu	993,525	62,270	48.6	34,145	1.95	1.03	0.15	1.39	47.0	6.7	63.2
23	Japan	Chiba	924,319	44,473	71.8	39,433	2.04	0.68	0.55	0.89	30.8	25.2	40.5
24	China	Hong Kong	6,720,000	23,497	286.0	27,600	2.57	0.42	1.18	0.97	16.2	46.0	37.8
25	Singapore	Singapore	3,320,000	32,549	102.0	28,900	2.87	1.29	1.17	0.40	45.1	40.9	14.0
26	Arab	Dubai	910,000	27,083	33.6	22,000	2.56	1.98	0.17	0.41	77.3	6.7	16.0
27	Australia	Melbourne	3,370,000	245,985	13.7	22,800	3.72	2.83	0.22	0.67	76.0	6.0	18.0

Table B-1 Database on the current research in the region of Korean, Japan and Wealthy Asian: (27cities)-*continuous. 1*

No	Nation	Urban	Average daily distance travelled of a motorized trip	Average Distance of Private motorized mode	Average Speed of Private motorized mode	Average Duration of Private motorized mode	Average speed of Public transport mode	Average Distance of Public transport mode	Average Duration of Public transport mode	Average passenger car occupancy rate	Number of Private Passenger vehicle	Total length of Road	Total Length of Railway
unit			km/vehicle* day	km/trip	km/h	min/trip	km/h	km/trip	min/trip	person/ vehicle	vehicle/ 1000inhabitants	m/ 1000 inhabitants	m/ 1000 inhabitants
1	Korea	Seoul	39.1	13.2	20.8	38.1	22.8	17.5	46.0	1.51	215	781.4	27.9
2	Korea	Pusan	39.0	12.8	23.8	32.4	25.5	16.2	38.1	1.40	212	726.1	19.3
3	Korea	Daegu	40.1	12.1	24.9	29.2	25.9	16.3	37.8	1.57	269	901.5	11.2
4	Korea	Inchon	40.1	15.0	24.5	36.7	26.5	21.6	48.9	1.50	245	791.0	9.3
5	Korea	Kwangju	40.9	14.6	33.3	26.2	24.7	14.1	34.1	1.88	294	973.2	14.3
6	Korea	Daejeon	39.7	10.7	23.1	27.9	24.9	15.5	37.3	1.87	287	1,197.9	15.5
7	Korea	Ulsan	38.8	11.2	25.1	26.7	21.5	13.3	37.2	1.28	289	1,409.3	0.0
8	Korea	Suwon	35.3	13.3	28.5	27.9	21.3	18.1	50.8	1.43	276	918.9	7.3
9	Korea	Sungnam	31.6	11.4	23.9	28.7	16.1	11.8	44.1	1.43	263	594.1	30.8
10	Japan	Tokyo	33.7	13.9	27.7	30.0	28.2	22.1	47.1	1.14	345	1,393.7	39.9
11	Japan	Yokohama	28.4	12.1	28.0	26.0	33.7	33.5	59.6	1.13	287	2,141.7	14.2
12	Japan	Osaka	34.2	13.3	25.8	31.0	21.1	17.4	49.6	1.15	202	1,513.7	65.8
13	Japan	Nagoya	21.3	8.6	22.5	22.8	18.9	14.4	45.7	1.13	386	2,857.5	37.7
14	Japan	Sapporo	21.8	9.2	25.1	21.9	17.8	12.6	42.4	1.23	359	2,960.4	30.0
15	Japan	Kobe	32.1	13.1	27.9	28.1	24.6	22.6	55.0	1.25	265	3,851.2	27.3
16	Japan	Kyoto	24.8	9.9	22.8	26.0	23.7	23.6	59.7	1.22	256	2,410.5	40.0
17	Japan	Fukuoka	22.9	9.0	22.7	23.9	16.7	12.5	44.9	1.17	311	2,784.2	12.7
18	Japan	Kawasaki	27.6	10.6	25.0	25.5	33.5	33.3	59.6	1.19	239	1,860.1	0.8
19	Japan	Saitama	25.1	8.4	22.5	22.3	33.4	38.3	68.9	1.28	161	3,522.1	12.4
20	Japan	Hiroshima	26.5	10.9	24.5	26.5	19.2	15.0	46.9	1.25	320	3,736.8	46.2
21	Japan	Sendai	24.0	10.0	25.2	23.9	18.1	13.7	45.7	1.34	101	3,493.9	14.4
22	Japan	Kitakyushu	25.3	10.5	26.6	23.6	21.5	18.3	51.2	1.12	316	4,276.5	25.1
23	Japan	Chiba	24.2	9.1	24.8	21.9	33.5	39.5	70.7	1.17	352	3,518.4	15.4
24	China	Hong Kong	23.1	9.0	22.5	24.0	26.0	8.5	43.0	1.58	51	284.0	21.8
25	Singapore	Singapore	27.8	9.7	25.3	23.0	28.6	9.5	43.0	1.56	123	940.0	22.5
26	Arab	Dubai	28.2	11.0	44.0	15.0	27.8	9.0	35.0	1.50	243	3,100.0	0.0
27	Australia	Melbourne	37.2	10.0	31.7	18.9	31.7	10.0	18.9	1.26	578	6,623.0	65.1

Table B-1 Database on the current research in the region of Korean, Japan and Wealthy Asian: (27cities) -*continuous. 2*

No	Nation	Urban	Rail Dummy	Total No. of Station	Total Length of Railway	metro dummy	Metro Station	Metro Length	Tram dummy	Tram Station	Tram Length	Light rail dummy	LRT station	LRT Length	Traffic Density	**Transport Energy Consumption**
unit			1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	Vehicl e/m	**MJ/person**
1	Korea	Seoul	1	263	27.9	1	263	27.9	0	0	0.0	0	0	0.0	0.27	2,438.1
2	Korea	Pusan	1	73	19.3	1	73	19.3	0	0	0.0	0	0	0.0	0.29	8,230.6
3	Korea	Daegu	1	30	11.2	1	30	11.2	0	0	0.0	0	0	0.0	0.30	7,713.6
4	Korea	Inchon	1	22	9.3	1	22	9.3	0	0	0.0	0	0	0.0	0.31	7,371.6
5	Korea	Kwangju	1	20	14.3	1	20	14.3	0	0	0.0	0	0	0.0	0.30	7,359.1
6	Korea	Daejeon	1	22	15.5	1	22	15.5	0	0	0.0	0	0	0.0	0.24	6,425.2
7	Korea	Ulsan	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.20	9,784.9
8	Korea	Suwon	1	4	7.3	1	4	7.3	0	0	0.0	0	0	0.0	0.30	9,781.0
9	Korea	Sungnam	1	15	30.8	1	15	30.8	0	0	0.0	0	0	0.0	0.44	8,612.6
10	Japan	Tokyo	1	294	39.9	1	245	30.8	1	29	2.0	1	20	7.1	0.25	3,548.0
11	Japan	Yokohama	1	46	14.2	1	32	11.3	0	0	0.0	1	14	3.0	0.13	5,303.5
12	Japan	Osaka	1	163	65.8	1	98	47.1	1	41	7.1	1	24	11.6	0.13	2,147.8
13	Japan	Nagoya	1	80	37.7	1	80	37.7	0	0	0.0	0	0	0.0	0.13	6,812.2
14	Japan	Sapporo	1	72	30.0	1	49	25.5	1	23	4.5	0	0	0.0	0.12	6,191.4
15	Japan	Kobe	1	40	27.3	1	25	20.1	0	0	0.0	1	15	7.1	0.07	4,238.0
16	Japan	Kyoto	1	74	40.0	1	27	17.9	0	0	0.0	1	47	22.1	0.11	3,396.7
17	Japan	Fukuoka	1	19	12.7	1	19	12.7	0	0	0.0	0	0	0.0	0.11	6,278.7
18	Japan	Kawasaki	1	2	0.8	0	0	0.0	0	0	0.0	1	2	0.8	0.13	3,305.5
19	Japan	Saitama	1	8	12.4	1	8	12.4	0	0	0.0	0	0	0.0	0.05	4,000.7
20	Japan	Hiroshima	1	102	46.2	0	0	0.0	1	82	32.2	1	20	13.9	0.09	7,523.6
21	Japan	Sendai	1	17	14.4	1	17	14.4	0	0	0.0	0	0	0.0	0.03	7,115.7
22	Japan	Kitakyushu	1	13	25.1	0	0	0.0	0	0	0.0	1	13	25.1	0.07	8,298.0
23	Japan	Chiba	1	18	15.4	0	0	0.0	0	0	0.0	1	18	15.4	0.10	4,892.1
24	China	Hong Kong	1	70	21.8	1	70	21.8	0	0	0.0	0	0	0.0	0.18	2,561.9
25	Singapore	Singapore	1	56	22.5	1	42	20.2	0	0	0.0	1	14	2.3	0.13	8,139.1
26	Arab	Dubai	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.08	11,005.1
27	Australia	Melbourne	1	1773	65.1	0	0	0.0	1	1773	65.1	0	0	0.0	0.09	17,002.4

Table B-2 Database on the current research in the European region: (31cities)

No	Nation	Urban	Population	Urbanized Area	Urban Density	GRDP	Number of daily Trips	Daily mechanized trips per inhabitant (excluding walking)	Trip by PMM	Trip by PUB	Trip by NMM	Private motorized mode	Public Transport	Non-motorized mode
unit			persons	ha	inhabitants /ha	$/person	Trips/day *capita	Trips/day *capita	Trips/ day	Trips/ day	Trips/ day	%	%	%
28	Russia	Moscow	11,400,000	70,807	161.0	6,060	2.67	2.07	0.91	1.32	0.65	33.9	49.3	24.4
29	France	Paris	11,100,000	274,074	40.5	37,200	2.81	1.84	1.30	0.51	1.00	46.4	18.0	35.6
30	UK	London	7,170,000	130,601	54.9	36,400	2.65	1.86	1.33	0.50	0.82	50.2	18.8	31.1
31	Spain	Madrid	5,420,000	97,307	55.7	20,000	2.71	2.01	1.39	0.61	0.71	51.4	22.4	26.1
32	Spain	Barcelona	4,390,000	58,768	74.7	17,100	1.85	1.22	0.87	0.35	0.63	46.9	18.8	34.3
33	Greece	Athens	3,900,000	59,361	65.7	11,600	1.61	1.49	1.03	0.45	0.13	63.9	27.9	8.2
34	Germany	Berlin	2,930,000	61,974	54.7	20,300	3.05	2.26	1.20	0.75	1.10	39.3	24.6	36.2
35	Italy	Rome	2,810,000	44,888	62.6	26,600	2.19	1.68	1.23	0.44	0.52	56.2	20.2	23.6
36	Portugal	Lisbon	2,680,000	96,057	27.9	17,100	1.61	1.21	0.77	0.44	0.39	48.0	27.5	24.5
37	UK	Manchester	2,510,000	62,129	40.4	22,400	2.84	2.25	1.93	0.27	0.64	68.1	9.4	22.6
38	Germany	Stuttgart	2,380,000	67,422	35.3	32,300	3.28	2.54	1.93	0.36	0.99	58.9	11.0	30.1
39	UK	Glasgow	2,100,000	71,186	29.5	20,600	2.96	2.29	1.95	0.31	0.70	65.9	10.6	23.5
40	Sweden	Copenhagen	1,810,000	77,021	23.5	34,100	3.00	2.44	1.47	0.36	1.17	48.9	12.1	39.0
41	Denmark	Budapest	1,760,000	38,013	46.3	9,840	2.85	2.22	0.94	1.24	0.67	33.1	43.5	23.4
42	Hungary	Warsaw	1,690,000	32,816	51.5	13,200	2.26	1.82	0.65	1.17	0.45	28.6	51.6	19.8
43	Poland	Valencia	1,550,000	31,275	50.2	14,300	2.09	1.13	0.86	0.26	0.97	41.3	12.4	46.2
44	Austria	Vienna	1,550,000	23,169	66.9	34,300	2.70	1.97	0.97	0.92	0.81	36.0	34.0	30.0
45	Italy	Turin	1,470,000	31,887	46.1	26,700	1.82	1.39	0.98	0.38	0.45	54.0	21.1	24.8
46	Germany	Munich	1,250,000	23,946	52.2	45,800	3.20	2.30	1.30	0.70	1.20	40.6	21.9	37.5
47	Netherlands	Rotterdam	1,180,000	28,502	41.4	28,000	2.74	2.11	1.32	0.27	1.15	48.3	9.7	41.9
48	France	Lyon	1,180,000	29,500	40.0	27,100	3.37	2.29	1.83	0.44	1.10	54.3	13.0	32.7
49	Czech Republic	Prague	1,160,000	26,364	44.0	15,100	3.71	2.96	1.32	1.61	0.78	35.6	43.3	21.1
50	Spain	Bilbao	1,120,000	21,580	51.9	20,500	1.95	1.02	0.69	0.31	0.95	35.4	16.0	48.6
51	Spain	Seville	1,120,000	21,918	51.1	11,000	1.85	1.09	0.89	0.19	0.77	48.0	10.4	41.6
52	France	Lille	1,100,000	20,000	55.0	21,800	3.59	2.55	2.27	0.22	1.10	63.2	6.1	30.7
53	UK	Newcastle	1,080,000	25,412	42.5	18,400	2.52	1.88	1.44	0.41	0.68	57.1	16.1	26.8
54	Norway	Oslo	981,000	37,586	26.1	42,900	3.18	2.51	1.88	0.49	0.81	59.1	15.4	25.5
55	Finland	Helsinki	969,000	22,023	44.0	36,500	3.10	2.41	1.36	0.84	0.90	44.0	27.0	29.0
56	Belgium	Brussels	964,000	13,098	73.6	23,900	2.82	2.08	1.66	0.38	0.78	58.9	13.6	27.5
57	Netherlands	Amsterdam	850,000	14,834	57.3	34,100	2.90	2.15	0.98	0.43	1.49	33.9	14.7	51.4
58	Switzerland	Zurich	809,000	18,180	44.5	41,600	3.18	2.37	1.48	0.73	0.97	46.4	23.0	30.5

Table B-2 Database on the current research in the European region: (31cities)-*continuous.1*

No	Nation	Urban	Average daily distance travelled of a motorized trip	Average Distance of Private motorized mode	Average Speed of Private motorized mode	Average Duration of Private motorized mode	Average speed of Public transport mode	Average Distance of Public transport mode	Average Duration of Public transport mode	Average passenger car occupancy rate	Number of Private Passenger vehicle	Total length of Road	Total Length of Railway
unit			km/vehicle* day	km/trip	km/h	min/trip	km/h	km/trip	min/trip	person/ vehicle	vehicle/ 1000inha bitants	m/ 1000 inhabitants	m/ 1000 inhabitants
28	Russia	Moscow	32.0	12.0	27.0	27.0	36.6	11.0	31.0	1.70	189	406.0	60.9
29	France	Paris	23.1	8.2	22.0	22.0	30.9	11.4	45.0	1.28	439	1,980.0	22.3
30	UK	London	23.9	9.0	23.0	24.0	34.6	12.0	34.0	1.34	343	889.0	64.4
31	Spain	Madrid	29.8	11.0	30.0	22.0	30.7	10.5	37.0	1.32	478	4,870.0	41.9
32	Spain	Barcelona	20.0	10.8	26.0	24.6	36.3	9.0	35.1	1.35	424	2,100.0	19.7
33	Greece	Athens	16.1	10.0	20.0	30.0	25.1	6.5	44.0	1.30	385	2,310.0	18.5
34	Germany	Berlin	25.3	8.3	24.0	21.0	30.1	10.9	26.0	1.32	328	1,570.0	116.1
35	Italy	Rome	26.3	12.0	23.0	32.0	27.7	9.0	48.0	1.30	689	2,800.0	26.9
36	Portugal	Lisbon	13.4	8.3	20.0	25.0	22.8	11.1	55.0	1.20	432	889.0	29.5
37	UK	Manchester	22.7	8.0	32.0	15.0	23.1	7.0	27.0	1.35	434	3,700.0	14.9
38	Germany	Stuttgart	36.1	11.0	37.0	18.0	39.9	8.0	12.0	1.30	566	1,190.0	50.5
39	UK	Glasgow	23.7	8.0	28.0	17.0	30.7	8.5	28.0	1.35	345	5,800.0	5.0
40	Sweden	Copenhagen	39.0	13.0	39.0	20.0	41.8	12.0	30.0	1.49	315	3,850.0	257.0
41	Denmark	Budapest	25.7	9.0	20.0	27.0	21.2	7.0	32.0	1.20	329	2,430.0	148.4
42	Hungary	Warsaw	22.6	10.0	25.0	24.0	23.1	9.2	24.0	1.30	380	1,680.0	98.8
43	Poland	Valencia	24.0	11.5	24.0	28.7	27.5	8.7	19.0	1.30	466	2,870.0	146.2
44	Austria	Vienna	22.4	8.3	24.0	21.0	27.0	7.0	27.0	1.30	414	1,810.0	177.1
45	Italy	Turin	17.1	9.4	22.0	26.0	19.1	6.6	40.5	1.20	637	2,710.0	84.4
46	Germany	Munich	48.0	15.0	30.0	30.0	39.4	10.0	35.0	1.25	542	1,830.0	125.8
47	Netherlands	Rotterdam	24.7	9.0	25.0	22.0	28.8	8.5	17.7	1.29	356	4,070.0	151.2
48	France	Lyon	21.6	6.4	20.0	19.0	24.6	5.1	34.0	1.29	489	2,470.0	44.3
49	Czech Republic	Prague	29.7	8.0	25.0	19.0	28.6	7.0	26.0	1.40	536	2,910.0	506.0
50	Spain	Bilbao	29.1	14.9	33.0	26.8	32.1	10.0	34.4	1.30	392	4,360.0	57.9
51	Spain	Seville	14.8	8.0	21.0	23.0	18.4	6.0	35.0	1.20	406	2,020.0	43.4
52	France	Lille	19.4	5.4	20.0	16.0	29.0	6.7	36.0	1.32	413	3,480.0	57.8
53	UK	Newcastle	24.7	9.8	36.0	16.4	23.3	7.2	27.6	1.32	320	4,120.0	68.5
54	Norway	Oslo	28.6	9.0	36.0	15.0	40.4	9.0	35.0	1.30	418	5,860.0	269.3
55	Finland	Helsinki	25.4	8.2	33.0	15.0	32.9	7.2	27.0	1.25	361	3,610.0	108.0
56	Belgium	Brussels	28.5	10.1	28.0	22.0	27.9	8.5	35.0	1.36	497	1,940.0	173.8
57	Netherlands	Amsterdam	31.9	11.0	29.0	23.0	20.0	11.0	33.0	1.34	336	2,750.0	190.2
58	Switzerland	Zurich	37.5	11.8	32.0	22.0	40.8	11.8	17.4	1.41	495	4,700.0	135.1

Table B-2 Database on the current research in the European region: (31cities)-*continuous.2*

No	Nation	Urban	Rail Dummy	Total No. of Station	Total Length of Railway	metro dummy	Metro Station	Metro Length	Tram dummy	Tram Station	Tram Length	Light rail dummy	LRT station	LRT Length	Traffic Density	**Transport Energy Consumption**
unit			1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	Vehicle/m	MJ/person
28	Russia	Moscow	1	805	60.9	1	165	23.6	1	640	37.3	0	0	0.0	0.47	6,250.7
29	France	Paris	1	374	22.3	1	297	18.2	1	43	2.3	1	34	1.8	0.22	9,187.5
30	UK	London	1	347	64.4	1	275	56.9	1	38	3.9	1	34	3.6	0.39	9,560.4
31	Spain	Madrid	1	237	41.9	1	237	41.9	0	0	0.0	0	0	0.0	0.10	10,719.2
32	Spain	Barcelona	1	123	19.7	1	123	19.7	0	0	0.0	0	0	0.0	0.20	6,934.3
33	Greece	Athens	1	52	18.5	1	52	18.5	0	0	0.0	0	0	0.0	0.17	9,168.7
34	Germany	Berlin	1	547	116.1	1	170	52.0	1	377	64.1	0	0	0.0	0.21	7,873.8
35	Italy	Rome	1	241	26.9	1	49	13.0	1	192	13.9	0	0	0.0	0.25	12,156.5
36	Portugal	Lisbon	1	130	29.5	1	41	11.6	1	89	17.9	0	0	0.0	0.49	6,192.8
37	UK	Manchester	1	37	14.9	0	0	0.0	1	37	14.9	1	0	0.0	0.12	10,221.8
38	Germany	Stuttgart	1	187	50.5	0	0	0.0	0	0	0.0	1	187	50.5	0.48	13,514.2
39	UK	Glasgow	1	15	5.0	1	15	5.0	0	0	0.0	0	0	0.0	0.06	11,084.5
40	Sweden	Copenhage n	1	0	257.0	0	0	0.0	0	0	0.0	0	0	0.0	0.08	10,305.8
41	Denmark	Budapest	1	757	148.4	1	78	17.8	1	679	130.6	0	0	0.0	0.14	8,197.0
42	Hungary	Warsaw	1	564	98.8	1	16	10.1	1	520	71.6	1	28	17.2	0.23	5,076.8
43	Poland	Valencia	1	146	146.2	1	109	86.1	1	37	60.1	0	0	0.0	0.16	7,965.3
44	Austria	Vienna	1	1,219	177.1	1	62	28.1	1	1,133	118.1	1	24	30.8	0.23	6,483.2
45	Italy	Turin	1	0	84.4	0	0	0.0	1	0	71.3	0	0	13.1	0.24	8,447.4
46	Germany	Munich	1	237	125.8	1	90	68.8	1	147	57.0	0	0	0.0	0.30	14,396.9
47	Netherlands	Rotterdam	1	342	151.2	1	48	72.0	1	294	79.2	0	0	0.0	0.09	9,427.8
48	France	Lyon	1	91	44.3	1	42	24.7	1	49	19.7	0	0	0.0	0.20	10,518.2
49	Czech Republic	Prague	1	665	506.0	1	53	46.6	1	612	459.5	0	0	0.0	0.18	7,706.3
50	Spain	Bilbao	1	32	57.9	1	32	57.9	0	0	0.0	0	0	0.0	0.09	6,941.8
51	Spain	Seville	1	0	43.4	0	0	0.0	0	0	0.0	0	0	0.0	0.20	6,670.0
52	France	Lille	1	96	57.8	1	60	40.9	1	36	16.9	0	0	0.0	0.12	10,753.6
53	UK	Newcastle	1	58	68.5	1	58	68.5	0	0	0.0	0	0	0.0	0.08	8,956.2
54	Norway	Oslo	1	207	269.3	1	101	121.0	1	106	148.3	0	0	0.0	0.07	10,908.1
55	Finland	Helsinki	1	282	108.0	1	16	21.9	1	266	86.2	0	0	0.0	0.10	7,850.7
56	Belgium	Brussels	1	69	173.8	1	52	35.2	1	17	138.6	0	0	0.0	0.26	11,828.4
57	Netherlands	Amsterdam	1	811	190.2	1	49	95.5	1	762	94.7	0	0	0.0	0.12	7,591.3
58	Switzerland	Zurich	1	168	135.1	0	0	0.0	1	168	135.1	0	0	0.0	0.11	11,013.2

Table B-3 Database on the current research in the US region: (46cities)

No	Nation	Urban	Population	Urbanized Area	Urban Density	GRDP	Number of daily Trips	Trip by PMM	Trip by PUB	Trip by NMM	Private motorized mode	Public Transport	Non-motorized mode
unit			persons	ha	inhabitants/ha	$/person	Trips/day *capita	Trips/ day	Trips/ day	Trips/ day	%	%	%
59	USA	New York	18,490,029	1740,500	14.5	48,566	3.36	2.01	0.27	0.74	59.9	8.1	22.2
60	USA	Los Angeles -Long Beach -Santa Ana	12,540,000	581,193	21.6	40,403	3.74	2.94	0.06	0.48	78.7	1.6	12.8
61	USA	Chicago	8,140,000	549,854	14.8	43,095	3.51	2.66	0.13	0.43	75.8	3.6	12.3
62	USA	Philadelphia	5,300,000	465,680	11.4	42,368	4.03	2.79	0.22	0.49	69.3	5.4	12.3
63	USA	Dallas -Fort Worth Arlington	4,445,000	364,152	12.2	47,628	3.63	2.84	0.03	0.20	78.1	0.7	5.4
64	USA	Miami-Fort Lauderdale	5,330,000	289,043	18.4	35,001	2.91	2.41	0.11	0.23	83.0	3.8	7.8
65	USA	Washington	4,280,000	299,662	14.3	53,667	4.23	2.91	0.21	0.48	68.8	4.9	11.5
66	USA	Houston	3,790,000	335,144	11.3	47,487	3.46	2.82	0.04	0.16	81.5	1.3	4.6
67	USA	Detroit	4,055,000	326,339	12.4	40,918	4.08	3.05	0.07	0.39	74.7	1.8	9.5
68	USA	Boston	4,075,000	549,854	7.4	51,930	4.35	3.20	0.22	0.47	73.7	5.0	10.8
69	USA	Atlanta	4,170,000	508,415	8.2	45,748	4.10	3.18	0.11	0.27	77.4	2.7	6.5
70	USA	San Francisco -Oakland	4,140,000	248,898	16.6	55,094	3.86	2.99	0.11	0.46	77.4	2.8	11.9
71	USA	Phoenix	3,270,000	206,940	15.8	36,984	3.93	2.95	0.10	0.44	75.0	2.5	11.1
72	USA	Seattle	3,005,000	246,567	12.2	50,319	4.82	3.45	0.16	0.53	71.6	3.3	11.0
73	USA	Minneapolis -St. Paul	2,520,000	231,545	10.9	47,204	4.56	3.29	0.13	0.37	72.2	2.8	8.0
74	USA	San Diego	2,905,000	202,278	14.4	39,181	3.98	3.14	0.09	0.44	78.9	2.4	11.0
75	USA	St. Louis	2,105,000	214,192	9.8	35,919	4.06	2.92	0.06	0.29	71.8	1.5	7.2
76	USA	Baltimore	2,315,000	176,896	13.1	37,196	4.23	2.91	0.21	0.48	68.8	4.9	11.5
77	USA	Pittsburgh	1,800,000	220,667	8.2	35,617	3.68	2.25	0.18	0.44	61.1	4.8	11.9
78	USA	Tampa-St. Petersburg	2,250,000	207,717	10.8	31,663	3.88	3.02	0.03	0.29	77.8	0.7	7.5
79	USA	Denver Aurora	2,090,000	129,240	16.2	49,076	4.36	3.45	0.08	0.41	79.0	1.7	9.5

No	Nation	Urban	Population	Urbanized Area	Urban Density	GRDP	Number of daily Trips	Trip by PMM	Trip by PUB	Trip by NMM	Private motorized mode	Public Transport	Non-motorized mode
unit			persons	ha	inhabitants /ha	$/person	Trips/day *capita	Trips/ day	Trips/ day	Trips/ day	%	%	%
80	USA	Cleveland	1,790,000	167,054	10.7	39,151	4.03	2.83	0.12	0.32	70.4	2.9	7.9
81	USA	Cincinnati	1,620,000	173,788	9.3	37,323	4.36	3.09	0.07	0.35	70.8	1.5	8.0
82	USA	Portland	1,730,000	122,506	14.1	39,060	3.62	2.51	0.07	0.40	69.3	2.0	11.2
83	USA	Kansas City	1,500,000	151,255	9.9	41,024	4.29	3.49	0.05	0.29	81.3	1.1	6.7
84	USA	Sacramento	1,750,000	95,312	18.4	33,163	4.14	3.03	0.08	0.48	73.2	1.8	11.7
85	USA	San Antonio	1,360,000	105,154	12.9	30,005	3.30	2.49	0.06	0.14	75.3	1.9	4.2
86	USA	Orlando	1,360,000	117,326	11.6	37,394	3.74	3.01	0.04	0.31	80.6	1.0	8.4
87	USA	Columbus	1,195,000	102,305	11.7	41,218	4.23	1.72	0.03	0.23	67.1	1.2	8.9
88	USA	Providence	1,245,000	130,276	9.6	30,340	3.64	2.89	0.07	0.25	79.4	1.9	6.9
89	USA	Norfolk-VA Beach-Newport News	1,540,000	136,233	11.3	32,662	4.49	3.43	0.11	0.44	76.3	2.4	9.8
90	USA	Indianapolis	1,035,000	143,226	7.2	45,679	3.80	2.77	0.10	0.23	72.8	2.8	6.0
91	USA	Milwaukee	1,460,000	126,132	11.6	42,352	3.49	2.62	0.09	0.28	75.2	2.5	8.2
92	USA	Charlotte	860,000	112,405	7.7	58,797	4.78	3.52	0.10	0.41	73.8	2.1	8.6
93	USA	New Orleans	1,090,000	51,282	21.3	38,517	3.95	3.09	0.11	0.37	78.2	2.9	9.3
94	USA	Nashville-Davidson	990,000	111,628	8.9	39,946	4.67	3.39	0.01	0.41	72.7	0.2	8.7
95	USA	Austin	855,000	82,362	10.4	40,395	3.44	2.61	0.05	0.15	76.0	1.4	4.5
96	USA	Memphis	1,020,000	103,600	9.8	38,419	4.17	2.52	0.04	0.29	60.3	1.0	6.9
97	USA	Buffalo -Niagara Falls	1,130,000	94,794	11.9	28,301	3.81	2.80	0.11	0.39	73.5	3.0	10.4
98	USA	Louisville	905,000	101,269	8.9	36,762	3.80	3.15	0.04	0.21	83.1	1.0	5.5
99	USA	Hartford	890,000	121,211	7.3	17,419	3.45	2.72	0.06	0.24	79.1	1.6	6.8
100	USA	Jacksonville	990,000	106,449	9.3	25,901	5.18	3.71	0.06	0.39	71.5	1.1	7.4
101	USA	Oklahoma City	850,000	83,398	10.2	32,439	3.49	2.42	0.03	0.28	69.4	0.8	8.0
102	USA	Rochester	1,041,000	76,146	13.7	36,431	4.03	2.49	0.12	0.34	61.9	3.1	8.3
103	USA	Salt Lake City	970,000	59,570	16.3	42,484	3.38	2.70	0.08	0.34	79.7	2.4	10.2
104	USA	Honolulu	876,000	39,627	22.1	36,181	3.18	2.65	0.10	0.22	83.5	3.1	7.0

Table B-3 Database on the current research in the US region: (46cities)-*continuous.1*

No	Nation	Urban	Average daily distance travelled of a motorized trip	Average Distance of Private motorized mode	Average Speed of Private motorized mode	Average Duration of Private motorized mode	Average speed of Public transport mode	Average Distance of Public transport mode	Average Duration of Public transport mode	Average passenger car occupancy rate	Number of Private Passenger vehicle	Total length of Road	Total Length of Railway
unit			km/vehicle *day	km/trip	km/h	min/trip	km/h	km/trip	min/trip	person/ vehicle	vehicle/ 1000 inhabitants	m/ 1000 inhabitants	m/ 1000 inhabitants
59	USA	New York	25.1	12.9	39.0	19.9	20.0	17.3	51.8	1.66	460	3,539.0	23.4
60	USA	Los Angeles -Long Beach -Santa Ana	35.4	13.6	42.4	19.2	25.1	23.1	55.3	1.98	516	3,413.0	6.8
61	USA	Chicago	33.4	12.3	38.6	19.1	25.9	21.6	49.9	1.91	488	4,973.0	21.3
62	USA	Philadelphia	29.4	12.9	40.3	19.3	19.3	16.7	52.1	1.56	475	5,053.0	29.3
63	USA	Dallas -Fort Worth Arlington	45.3	16.6	46.9	21.2	12.5	13.9	66.6	1.95	483	7,592.0	16.0
64	USA	Miami-Fort Lauderdale	33.0	12.6	36.6	20.6	18.7	12.2	39.0	1.66	427	4,725.0	6.8
65	USA	Washington	36.0	15.8	42.9	22.0	25.2	19.8	47.2	1.70	475	4,509.0	38.8
66	USA	Houston	60.3	16.4	46.2	21.3	19.6	15.0	46.0	1.94	511	9,873.0	0.0
67	USA	Detroit	39.7	14.7	45.8	19.2	15.2	7.9	31.2	2.03	483	5,790.0	1.1
68	USA	Boston	31.7	12.7	42.1	18.2	22.6	15.6	41.3	1.78	543	5,426.0	42.4
69	USA	Atlanta	57.0	15.6	45.3	20.6	20.5	13.6	39.7	1.88	509	7,624.0	15.1
70	USA	San Francisco -Oakland	34.4	14.4	44.4	19.5	20.9	17.1	49.1	1.78	597	3,693.0	50.5
71	USA	Phoenix	32.8	14.0	46.2	18.1	22.8	22.9	60.2	1.84	389	5,392.0	0.0
72	USA	Seattle	39.7	14.2	41.6	20.4	23.6	13.9	35.3	1.73	509	5,436.0	2.0
73	USA	Minneapolis -St. Paul	40.8	14.8	46.8	19.0	20.5	16.5	48.3	1.76	555	7,348.0	7.8
74	USA	San Diego	38.9	13.8	44.8	18.4	14.1	13.5	57.1	1.73	566	3,700.0	25.7
75	USA	St. Louis	46.1	16.4	46.7	21.1	23.1	21.4	55.7	1.86	615	7,166.0	29.0
76	USA	Baltimore	33.6	15.8	42.9	22.0	25.2	19.8	47.2	1.70	468	4,832.0	27.7
77	USA	Pittsburgh	36.3	16.4	42.8	23.0	27.2	17.7	39.1	1.28	655	8,690.0	21.2
78	USA	Tampa-St. Petersburg	42.4	13.2	40.6	19.5	28.8	27.8	58.1	1.59	543	7,980.0	1.7
79	USA	Denver Aurora	36.2	14.3	43.2	19.9	34.8	27.6	47.5	1.74	195	5,682.0	4.1

No	Nation	Urban	Average daily distance travelled of a motorized trip	Average Distance of Private motorized mode	Average Speed of Private motorized mode	Average Duration of Private motorized mode	Average speed of Public transport mode	Average Distance of Public transport mode	Average Duration of Public transport mode	Average passenger car occupancy rate	Number of Private Passenger vehicle	Total length of Road	Total Length of Railway
unit			km/vehicle *day	km/trip	km/h	min/trip	km/h	km/trip	min/trip	person/ vehicle	vehicle/ 1000 inhabitants	m/ 1000 inhabitants	m/ 1000 inhabitants
80	USA	Cleveland	32.8	13.8	43.8	18.8	21.4	20.4	57.1	1.60	687	5,000.0	49.9
81	USA	Cincinnati	45.0	15.5	43.4	21.4	36.0	53.8	89.6	1.85	594	6,717.0	0.0
82	USA	Portland	32.0	14.3	42.7	20.0	18.6	11.9	38.4	1.66	558	5,686.0	37.9
83	USA	Kansas City	46.7	13.1	45.4	17.3	16.7	11.9	42.8	1.66	181	8,779.0	0.0
84	USA	Sacramento	34.7	15.2	47.3	19.3	14.7	12.5	51.0	1.63	678	5,487.0	27.8
85	USA	San Antonio	42.6	15.5	42.4	21.9	27.9	22.9	49.1	1.98	502	7,144.0	0.0
86	USA	Orlando	52.8	13.2	40.8	19.5	21.4	13.9	38.9	1.84	573	7,893.0	0.0
87	USA	Columbus	44.3	14.7	43.9	20.0	13.8	12.1	52.7	1.46	161	5,828.0	0.0
88	USA	Providence	34.2	15.3	45.6	20.2	26.3	11.8	26.9	1.98	665	7,624.0	0.0
89	USA	Norfolk-VA Beach-Newport News	36.3	13.2	44.5	17.8	27.8	13.0	28.0	1.36	541	5,893.0	0.0
90	USA	Indianapolis	53.8	14.5	44.4	19.6	40.8	29.6	43.5	1.60	670	7,557.0	0.0
91	USA	Milwaukee	36.3	13.3	45.3	17.7	20.1	11.9	35.4	1.76	445	5,852.0	0.0
92	USA	Charlotte	47.2	14.6	43.5	20.1	19.1	11.6	36.3	2.28	665	6,637.0	0.0
93	USA	New Orleans	23.8	12.8	40.8	18.9	15.6	14.7	56.6	1.60	508	4,971.0	29.1
94	USA	Nashville -Davidson	54.9	16.2	48.7	20.0	24.0	15.9	39.8	1.82	638	7,114.0	0.0
95	USA	Austin	52.6	15.1	44.8	20.2	19.8	20.7	62.7	1.73	654	8,314.0	0.0
96	USA	Memphis	40.2	20.5	47.9	25.7	12.5	14.2	68.2	1.78	540	5,932.0	8.8
97	USA	Buffalo -Niagara Falls	31.0	11.8	39.3	18.0	18.6	11.6	37.3	1.78	518	5,790.0	8.8
98	USA	Louisville	42.7	12.2	40.5	18.1	20.9	11.2	32.0	1.76	567	7,363.0	0.0
99	USA	Hartford	42.9	15.0	46.9	19.2	28.8	16.4	34.1	1.42	769	6,932.0	0.0
100	USA	Jacksonville	48.2	15.2	43.8	20.8	24.4	14.6	36.0	1.65	588	8,566.0	0.0
101	USA	Oklahoma City	38.9	13.3	43.6	18.3	17.6	7.0	23.8	1.93	706	7,014.0	0.0
102	USA	Rochester	37.1	16.4	47.0	20.9	25.5	17.9	42.1	1.83	553	6,502.0	0.0
103	USA	Salt Lake City	41.8	11.2	43.5	15.5	23.6	18.3	46.6	1.71	468	6,485.0	33.2
104	USA	Honolulu	26.9	11.5	36.0	19.2	18.1	14.4	47.6	1.91	386	2,485.0	0.0

Table B-3 Database on the current research in the US region: (46cities)*-continuous.2*

No	Nation	Urban	Rail Dummy	Total No. of Station	Total Length of Railway	metro dummy	Metro Station	Metro Length	Tram dummy	Tram Station	Tram Length	Light rail dummy	LRT station	LRT Length	Traffic Density	**Transport Energy Consumption**
unit			1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	Vehicle/m	MJ/person
59	USA	New York	1	503	23.4	1	503	23.4	0	0	0.0	0	0	0.0	0.13	12,931.3
60	USA	Los Angeles -Long Beach -Santa Ana	1	46	6.8	1	16	2.2	0	0	0.0	1	30	4.5	0.15	16,217.5
61	USA	Chicago	1	144	21.3	1	144	21.3	0	0	0.0	0	0	0.0	0.10	14,113.1
62	USA	Philadelphia	1	136	29.3	1	82	7.7	1	8	11.5	1	46	10.1	0.09	18,737.7
63	USA	Dallas -Fort Worth Arlington	1	34	16.0	0	0	0.0	0	0	0.0	1	34	16.0	0.06	18,703.2
64	USA	Miami-Fort Lauderdale	1	22	6.8	1	22	6.8	0	0	0.0	0	0	0.0	0.09	15,488.0
65	USA	Washington	1	83	38.8	1	83	38.8	0	0	0.0	0	0	0.0	0.11	21,475.6
66	USA	Houston	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.05	18,691.7
67	USA	Detroit	1	13	1.1	0	0	0.0	0	0	0.0	1	13	1.1	0.08	17,229.3
68	USA	Boston	1	154	42.4	1	84	30.1	0	0	0.0	1	70	12.3	0.10	18,436.7
69	USA	Atlanta	1	36	15.1	1	36	15.1	0	0	0.0	0	0	0.0	0.07	20,591.1
70	USA	San Francisco -Oakland	1	109	50.5	1	43	40.3	1	66	10.1	0	0	0.0	0.16	19,197.4
71	USA	Phoenix	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.07	17,495.2
72	USA	Seattle	1	15	2.0	0	0	0.0	1	10	1.1	1	5	0.9	0.09	22,622.7
73	USA	Minneapolis -St. Paul	1	17	7.8	0	0	0.0	0	0	0.0	1	17	7.8	0.08	30,467.1
74	USA	San Diego	1	49	25.7	0	0	0.0	0	0	0.0	1	49	25.7	0.15	19,691.5
75	USA	St. Louis	1	28	29.0	0	0	0.0	0	0	0.0	1	28	29.0	0.09	20,056.5
76	USA	Baltimore	1	44	27.7	1	12	10.2	0	0	0.0	1	32	17.5	0.10	21,475.6
77	USA	Pittsburgh	1	25	21.2	0	0	0.0	0	0	0.0	1	25	21.2	0.08	22,705.9
78	USA	Tampa-St. Petersburg	1	8	1.7	0	0	0.0	0	0	0.0	1	8	1.7	0.07	20,229.9
79	USA	Denver Aurora	1	15	4.1	0	0	0.0	0	0	0.0	1	15	4.1	0.03	22,422.2

No	Nation	Urban	Rail Dummy	Total No. of Station	Total Length of Railway	metro dummy	Metro Station	Metro Length	Tram dummy	Tram Station	Tram Length	Light rail dummy	LRT station	LRT Length	Traffic Density	**Transport Energy Consumption**
unit			1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	Vehicle/m	MJ/person
80	USA	Cleveland	1	52	49.9	1	18	34.2	0	0	0.0	1	34	15.6	0.14	33,645.3
81	USA	Cincinnati	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.09	20,586.5
82	USA	Portland	1	96	37.9	0	0	0.0	1	32	2.3	1	64	35.6	0.10	17,286.7
83	USA	Kansas City	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.02	21,534.0
84	USA	Sacramento	1	42	27.8	0	0	0.0	0	0	0.0	1	42	27.8	0.12	21,760.7
85	USA	San Antonio	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.07	15,789.6
86	USA	Orlando	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.07	17,618.2
87	USA	Columbus	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.03	39,979.7
88	USA	Providence	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.09	17,509.9
89	USA	Norfolk-VA Beach-Newport News	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.09	26,342.9
90	USA	Indianapolis	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.09	19,724.7
91	USA	Milwaukee	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.08	15,595.8
92	USA	Charlotte	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.10	17,816.5
93	USA	New Orleans	1	0	29.1	0	0	0.0	1	0	29.1	0	0	0.0	0.10	20,239.7
94	USA	Nashville -Davidson	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.09	23,291.3
95	USA	Austin	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.08	18,045.0
96	USA	Memphis	1	34	8.8	0	0	0.0	1	34	8.8	0	0	0.0	0.09	22,356.9
97	USA	Buffalo -Niagara Falls	1	14	8.8	0	0	0.0	0	0	0.0	1	14	8.8	0.09	15,331.1
98	USA	Louisville	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.08	17,737.0
99	USA	Hartford	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.11	22,351.9
100	USA	Jacksonville	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.07	26,915.1
101	USA	Oklahoma City	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.10	13,237.1
102	USA	Rochester	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.09	17,288.4
103	USA	Salt Lake City	1	23	33.2	0	0	0.0	0	0	0.0	1	23	33.2	0.07	14,040.6
104	USA	Honolulu	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.16	13,551.5

Table B-4 Database on the current research in the regions of the developing countries: (15cities)

No	Nation	Urban	Population	Urbanized Area	Urban Density	GRDP	Number of daily Trips	Trip by PMM	Trip by PUB	Trip by NMM	Private motorized mode	Public Transport	Non-motorized mode
unit			persons	ha	inhabitants /ha	$/person	Trips/day *capita	Trips/ day	Trips/ day	Trips/ day	%	%	%
105	Malaysia	Kuala Lumpur	1,390,800	24,300	57.2	4,816	2.80	1.64	0.21	0.71	58.4	7.5	25.3
106	Philippines	Manila	9,454,000	63,600	148.6	1,030	2.39	0.79	0.41	1.08	32.9	17.3	45.0
107	Lebanon	Tripoli	305,732	3,800	87.1	3,990	2.13	1.07	0.31	0.75	50.1	14.3	35.4
108	Syria	Damascus	3,078,190	248,600	12.4	1,088	1.44	0.35	0.64	0.43	24.6	44.4	29.8
109	Nicaragua	Managua	1,200,000	346,500	3.5	620	1.99	0.73	0.69	0.56	36.6	35.0	28.1
110	Brazil	Bucharest	2,149,000	59,700	36.0	2,830	2.79	0.74	1.32	0.67	26.6	47.3	24.2
111	Romania	Chengdu	3,068,312	58,554	52.4	2,442	2.56	0.35	0.13	2.06	13.8	5.2	80.3
112	China	Sao Paulo	18,300,000	213,287	85.8	6,420	1.78	0.60	0.52	0.67	33.6	29.0	37.4
113	Vietnam	Ho Chi Minh	5,285,000	176,361	30.0	1,460	2.38	1.70	0.06	0.53	71.3	2.6	22.3
114	Vietnam	Hanoi	3,183,000	92,101	34.6	1,350	2.87	0.18	0.06	2.61	6.3	2.1	91.2
115	Cambodia	Phnom Penh	1,152,000	43,891	26.2	215	2.16	1.28	0.08	0.68	59.4	3.9	31.4
116	Egypt	Cairo	6,800,992	64,000	106.3	2,019	2.84	0.99	0.92	0.91	35.0	32.5	32.0
117	Indonesia	Jakarta	5,306,589	116,628	45.5	710	3.67	0.79	0.46	1.40	21.5	12.4	38.0
118	Peru	Lima	8,043,256	279,402	28.8	2,299	2.06	0.70	0.86	0.38	34.1	41.8	18.6
119	Kenya	Nairobi	4,041,900	69,600	58.1	421	1.83	0.45	0.07	0.70	24.5	3.8	38.0

Table B-4 Database on the current research in the regions of the developing countries: (15cities)- *continuous.1*

No	Nation	Urban	Average daily distance travelled of a motorized trip	Average Distance of Private motorized mode	Average Speed of Private motorized mode	Average Duration of Private motorized mode	Average speed of Public transport mode	Average Distance of Public transport mode	Average Duration of Public transport mode	Average passenger car occupancy rate	Number of Private Passenger vehicle	Total length of Road	Total Length of Railway
unit			km/vehicle* day	km/trip	km/h	min/trip	km/h	km/trip	min/trip	person/ vehicle	vehicle/ 1000 inhabitants	m/ 1000 inhabitants	m/ 1000 inhabitants
105	Malaysia	Kuala Lumpur	26.3	8.2	14.9	32.9	8.4	7.8	55.6	2.07	208	1,628.3	46.0
106	Philippines	Manila	26.8	7.5	10.0	44.8	10.5	9.8	56.1	2.50	85	146.3	3.3
107	Lebanon	Tripoli	22.2	13.7	37.4	22.0	37.4	15.2	24.3	1.82	282	427.5	0.0
108	Syria	Damascus	19.2	12.2	33.3	21.9	43.3	16.3	22.6	1.45	20	485.2	24.2
109	Nicaragua	Managua	27.5	14.5	26.0	33.4	23.0	17.2	44.9	1.62	43	993.0	0.0
110	Brazil	Bucharest	24.2	17.5	32.6	32.1	24.5	18.7	45.8	1.70	191	942.4	179.3
111	Romania	Chengdu	33.3	11.5	40.8	33.1	12.0	21.0	104.9	2.00	54	728.4	0.0
112	China	Sao Paulo	16.2	9.1	18.2	30.0	22.5	12.4	50.0	1.50	238	1,960.0	3.1
113	Vietnam	Ho Chi Minh	33.9	8.1	23.8	20.3	17.5	12.3	42.1	1.74	12	235.6	0.0
114	Vietnam	Hanoi	27.3	16.7	26.0	38.5	26.0	14.5	33.5	2.80	11	196.0	0.0
115	Cambodia	Phnom Penh	18.0	7.7	29.3	15.7	22.6	4.1	10.9	4.00	42	679.4	0.0
116	Egypt	Cairo	30.9	13.8	19.0	43.5	19.0	17.7	56.0	1.93	91	422.6	17.1
117	Indonesia	Jakarta	56.9	13.1	34.8	40.6	25.0	20.3	48.7	1.80	98	332.6	0.0
118	Peru	Lima	21.3	11.4	16.8	40.6	33.4	28.8	51.8	1.49	48	293.1	1.2
119	Kenya	Nairobi	29.2	32.3	34.1	65.3	30.2	32.2	63.9	1.70	51	238.1	0.0

Table B-4 Database on the current research in the regions of the developing countries: (15cities) - *continuous.2*

No	Nation	Urban	Rail Dummy	Total No. of Station	Total Length of Railway	metro dummy	Metro Station	Metro Length	Tram dummy	Tram Station	Tram Length	Light rail dummy	LRT station	LRT Length	Traffic Density	**Transport Energy Consumption**
unit			1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	1: presence 0: absence	station	m/ 1000 inhabitants	Vehicle/m	MJ/person
105	Malaysia	Kuala Lumpur	1	63	46.0	1	24	20.9	0	0	0.0	1	39	25.2	0.13	9,220.5
106	Philippines	Manila	1	26	3.3	0	0	0.0	0	0	0.0	1	26	3.3	0.58	5,297.6
107	Lebanon	Tripoli	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.66	2,445.0
108	Syria	Damascus	1	45	24.2	1	45	24.2	0	0	0.0	0	0	0.0	0.04	1,547.9
109	Nicaragua	Managua	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.04	5,276.5
110	Romania	Bucharest	1	598	179.3	1	43	27.7	1	*555*	151.6	0	0	0.0	0.20	6,712.5
111	China	Chengdu	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.07	1,747.3
112	Brazil	Sao Paulo	1	52	3.1	1	52	3.1	0	0	0.0	0	0	0.0	0.12	4,428.1
113	Vietnam	Ho Chi Minh	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.05	8,252.4
114	Vietnam	Hanoi	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.06	898.8
115	Cambodia	Phnom Penh	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.06	817.4
116	Egypt	Cairo	1	159	17.1	1	53	9.3	1	106	7.8	0	0	0.0	0.22	7,747.4
117	Indonesia	Jakarta	1	19	7.4	-	-	-	-	-	-	-	-	-	0.18	4,970.8
118	Peru	Lima	1	6	1.2	1	6	1.2	0	0	0.0	0	0	0.0	0.16	2,347.9
119	Kenya	Nairobi	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.22	3,856.6